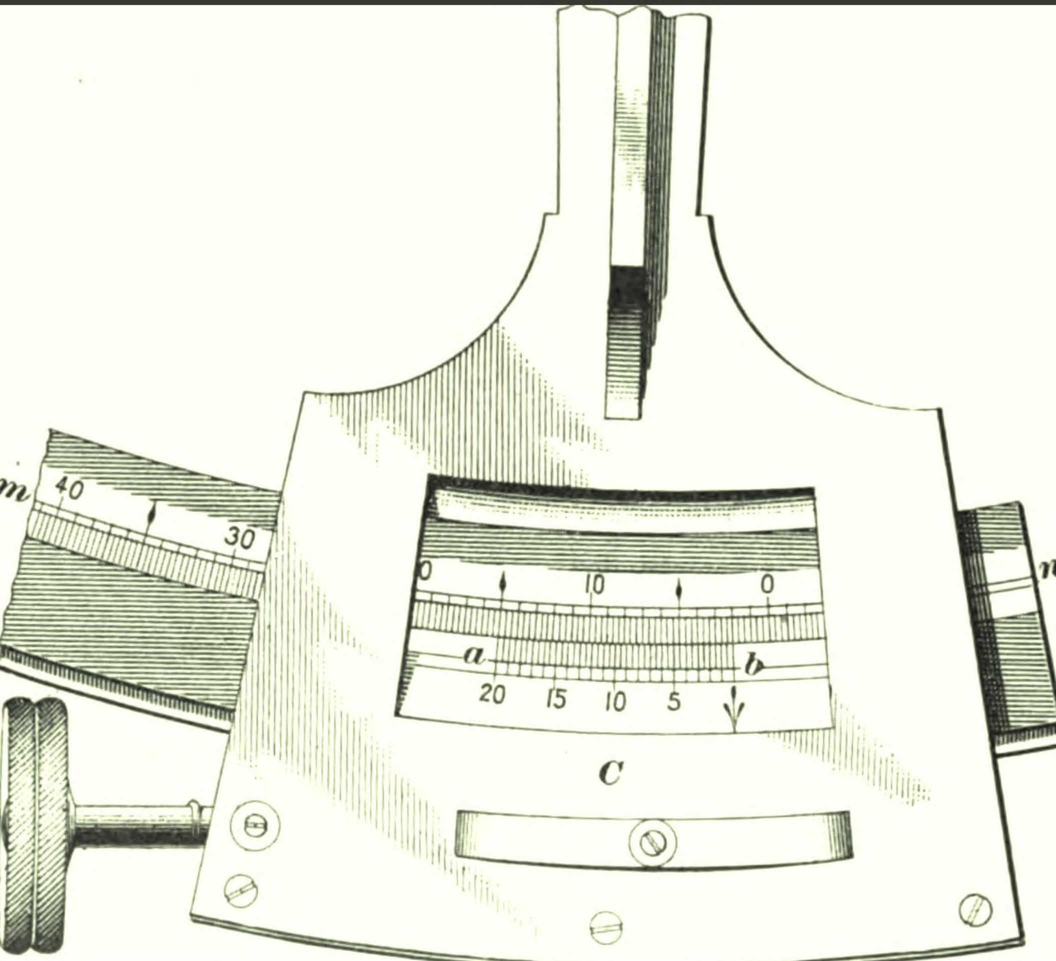

Nautical astronomy, latitude, longitude & azimuth, ...

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A SERIES OF TEXTBOOKS FOR PERSONS ENGAGED IN THE ENGINEERING PROFESSIONS AND TRADES OR FOR THOSE WHO DESIRE INFORMATION CONCERNING THEM. FULLY ILLUSTRATED AND CONTAINING NUMEROUS PRACTICAL EXAMPLES AND THEIR SOLUTIONS

NAUTICAL ASTRONOMY
LATITUDE
LONGITUDE AND AZIMUTH
SUMNER'S METHOD
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OCEAN METEOROLOGY
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PREFACE

The volumes of the International Library of Technology are made up of Instruction Papers, or Sections, comprising the various courses of instruction for students of the International Correspondence Schools. The original manuscript for each Instruction Paper is prepared by a person thoroughly qualified, both technically and by experience, to write with authority on his subject. In many cases the writer is regularly employed elsewhere in practical work and writes for us during spare time. The manuscripts are then carefully edited to make them suitable for correspondence work.

The only qualification for enrolment as a student in these Schools is the ability to read English and to write intelligibly the answers to the Examination Questions. Hence, our students are of all grades of education, and our Instruction Papers are, therefore, written in the simplest possible language so as to make them readily understood by all students. If technical expressions are essential to a thorough understanding of the subject, they are clearly explained when first introduced.

The great majority of our students wish to prepare themselves for advancement in their vocations or to qualify for other and more congenial occupations. Their time for study is usually after the day's work is done and is limited to a few hours each day. Therefore, every effort is made to give them practical and accurate information in clear, concise form, and to make this information include all of the essentials but none of the non-essentials. To effect this result derivations of rules and formulas are usually omitted, but thorough and complete instructions are given regarding how, when, and under what conditions any particular rule, formula, or process should be

applied. Whenever possible one or more examples, such as would be likely to arise in actual practice, together with their solutions, are given for illustration.

As the best way to make a statement, explanation, or description clear is to give a picture or a diagram in connection with it, illustrations are very freely used. These illustrations are especially made by our own Illustrating Department in order to adapt them fully to the requirements of the text. Projection drawings, sectional drawings, outline drawings, perspective drawings, partly shaded or full shaded, are employed, according to which will best produce the desired result. Half-tone engravings are used only in those cases where the general effect is desired rather than the actual details.

In the table of contents that immediately follows are given the titles of the Sections included in this volume, and under each title is listed the main topics discussed. At the end of the volume will be found a complete index, so that quick reference can be made to any subject treated.

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CONTENTS

NAUTICAL ASTRONOMY

(PART 1)

RUDIMENTS OF ASTRONOMY

DEFINITIONS AND PRINCIPLES

1. That branch of navigation by which the position of a ship at sea is determined by means of observations of the various celestial bodies, is called **nautical astronomy.** As its name implies, nautical astronomy is a special application of practical astronomy for nautical purposes. The problems and methods involved are identical with those practiced in astronomical observatories and by land surveyors for determining latitude and longitude, although the instruments used at sea are adapted to circumstances and conditions peculiar to navigation.

Before entering into the study of this branch of navigation, it is essential to possess a fair understanding of a number of facts and principles of which astronomy makes frequent use and on which are based the methods employed in nautical astronomy. A thorough acquaintance with this subject will materially assist in more readily grasping the underlying principles of processes by which latitude and longitude are found at sea by observations of celestial bodies.

DIVISIONS OF THE SCIENCE

2. The science of astronomy is conveniently divided into five branches; namely, *descriptive*, *spherical*, *practical*, *gravitational*, and *physical astronomy*.

3. Descriptive astronomy consists of an orderly statement of astronomical facts ascertained by systematic observation, and of the principles theoretically derived from these facts.

4. Spherical astronomy treats of the application of geometry and trigonometry to determine the relative positions of heavenly bodies—the earth included.

5. Practical astronomy treats of the methods of making astronomical observations and deducing from them the values of certain important quantities (latitude and longitude) used in navigation and surveying.

6. Gravitational astronomy, also called *celestial mechanics*, treats of the application of dynamic principles to account for the motions of the heavenly bodies.

7. Physical astronomy, which is also known as *astrophysics*, treats of the physical conditions, chemical constitution, and temperature of the heavenly bodies.

From the foregoing, it will be noticed that nautical astronomy is essentially based on the principles of that part of the science known as practical astronomy, and these principles, and facts having a direct bearing on them, will consequently be fully treated in this Section.

THE CELESTIAL SPHERE

8. To an observer of the heavens at night, the celestial bodies appear to be bright, equidistant points attached to the inner surface of a vast, hollow, spherical dome, the center of which is at the observer's eye. A little reflection, however, is sufficient to establish the fact that the heavenly

bodies are not all equidistant from the observer's eye, and are not attached to any surface, spherical or otherwise.

Except in a few cases, there are no direct means of estimating the distance of these bodies, and most astronomical instruments determine merely their relative directions. It is very important, therefore, to have a convenient mode of representing these relative directions. The imaginary spherical surface, which apparently encloses all the heavenly bodies and which has its center at the observer's eye, is called the **celestial sphere.** On this surface, circles are imagined to be drawn just as parallels of latitude and meridians of longitude are drawn on the terrestrial sphere. By referring to these circles of the celestial sphere, positions and motions of the heavenly bodies may be determined and recorded.

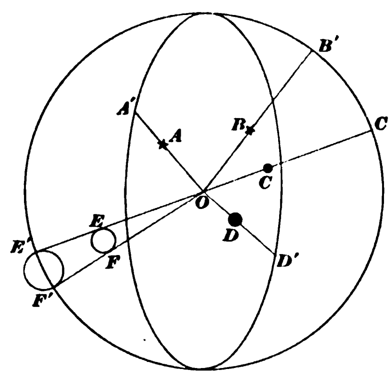


Fig. 1

Let O, Fig. 1, be the position of the observer's eye, and, consequently, the center of the celestial sphere $A' B' C' D'$. Let A, B, C, and D be any heavenly bodies. Imagine the lines OA, OB, OC, and OD drawn and produced to meet the celestial sphere in the points A', B', C', and D'. The apparent positions of the bodies A, B, C, and D depend only on their directions, and are independent of their distances from O. Therefore, the positions of A, B, C, and D as they appear to the observer at O are correctly represented by the points A', B', C', and D' on the celestial sphere.

9. Angular Distance.—Let $B' C' F' E'$, Fig. 1, be a great circle of the celestial sphere. Then the arc $B' C'$ is measured by the angle $B' O C'$, or $B O C$. Hence, the arc $B' C'$ of the celestial sphere, or the angle $B O C$, is called the **angular distance** between the bodies B and C, and is

usually expressed in degrees, minutes, and seconds. The angular distance should not be confused with the actual linear distance BC. If the angular distance BOC were known, it would also be necessary to know the distances OB and OC before the linear distance BC could be determined.

10. Angular Diameter.—If EF, Fig. 1, is the diameter of a distant globe, such as the sun or the moon, the angle EOF is called its **angular diameter.** This angular diameter is measured by the arc $E'F'$ of the celestial sphere.

11. Relation Between Distance and Apparent Size. Let AB, Fig. 2, be the radius of a globe, and let o be the

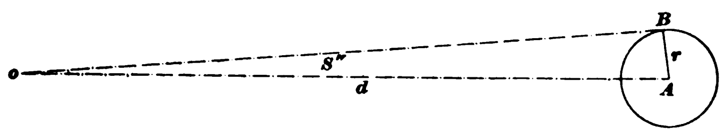


FIG. 2

position of the observer's eye. Then the angle AoB is the angular semi-diameter of the globe as seen from o. If the angle AoB contains S seconds, then, by trigonometry,

$$\sin AoB = \sin S'' = \frac{r}{d} \qquad (1)$$

Now, if the angle AoB is very small, it can be shown that

$$\sin S'' = \frac{S}{206{,}265} \text{ (very nearly)}$$

Whence, $$S = 206{,}265\,\frac{r}{d} \qquad (2)$$

Hence, the angular semi-diameter of any body varies directly as its linear semi-diameter r, and inversely as its distance d.

12. Center of the Celestial Sphere.—If a dot is made with a pencil to represent the center of a circle drawn on paper, that dot is not a true mathematical point, but has some size; yet the magnitude of the dot is so small compared with the magnitude of the circle, that, for all practical purposes, any mathematical point covered by the dot may be regarded as the center of the circle. In a like manner, the diameter of the earth is utterly insignificant in comparison

with the distances of most of the heavenly bodies; and, therefore the size of the earth is insignificant in comparison with the size of the celestial sphere that is assumed to enclose all the heavenly bodies. For astronomical purposes, it is therefore convenient to consider the center of the celestial sphere to be at the center of the earth, as shown in Fig 3.

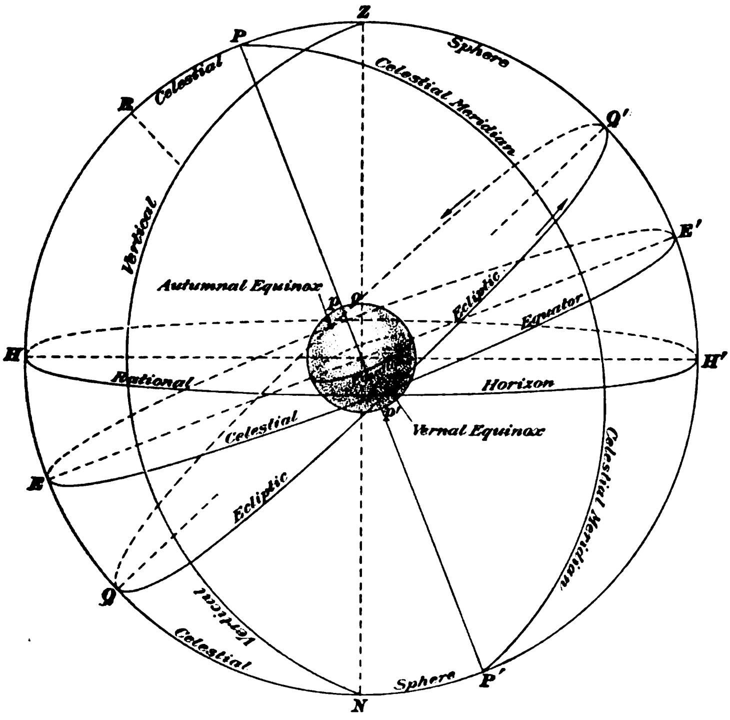


FIG. 3

13. Celestial Poles.—The position of the **celestial poles** P and P', Fig. 3, is indicated by the prolongation of the axis pp' of the earth. In other words, the direction of the earth's axis defines the points in the sky where the celestial poles are situated.

14. Celestial Equator.—If the plane of the earth's equator were extended indefinitely on all sides toward the

sky, its intersection with the celestial sphere would indicate what is known as the **equinoctial,** or the **celestial equator.** Or, the celestial equator may be defined as the great circle EE', Fig. 3, the plane of which is perpendicular to the axis PP' and the center of which passes through or coincides with the center of the earth.

15. Zenith and Nadir.—The point Z, Fig. 3, of the celestial sphere directly or vertically above the head of an observer at o is called the **zenith.** The zenith of any point on the surface of the earth is indicated by the direction of the plumb-line at that point. The point N of the celestial sphere directly underneath the observer at o is called the **nadir.** This latter point, however, is seldom used in practical astronomy.

16. Rational Horizon.—The **rational horizon** is a great circle HH', Fig. 3, the plane of which passes through the center of the earth perpendicular to the line connecting the observer's zenith with the center of the earth. The rational horizon is also known as the *true horizon.*

17. Ecliptic.—The great circle QQ', Fig. 3, that the sun's apparent path describes on the celestial sphere is called the **ecliptic.** This circle is inclined to the celestial equator, and consequently to the geographical equator, at an angle that may be assumed to be 23° 27′, crossing it at opposite points called the *equinoctial points.* In reality, this path is described by the earth about the sun, a fact that will be considered later.

18. In the succeeding articles, it will be shown that these three great circles—the rational horizon, the celestial equator, and the ecliptic—form the foundation, or coordinates, of three important systems that are used for the purpose of locating a point, or position, on the celestial sphere.

SYSTEMS OF THE CELESTIAL SPHERE

19. As explained in *Trigonometry*, the position of a point on a sphere is determined by measuring an arc of a fixed great circle and an arc of a secondary to that great circle. Any fixed great circle and its secondary constitute a system of circles of the sphere, and any such system can be used to define the position of a point on the sphere.

TABLE I

CIRCLES AND POINTS OF THE CELESTIAL SPHERE

	Horizon System	Equinoctial System	Ecliptic System
Primary Circle	Rational Horizon	Equinoctial, or Celestial Equator	Ecliptic
Secondaries	Verticals	Hour Circles	Circles of Celestial Longitude
Secondaries Having Special Names	Prime Vertical, The Meridian	Equinoctial Colure, Solstitial Colure	
Points	Zenith, Nadir	Celestial Poles, Equinoctial Points	Poles of the Ecliptic, Equinoctial Points, Solstitial Points
Measurements	{Altitude, Azimuth} {Zenith Distance, Amplitude}	{Right Ascension, Declination} {Hour Angle, Polar Distance}	Celestial Longitude, Celestial Latitude
Parallels		Declination Parallels	Parallels of Celestial Latitude

NOTE.—For the sake of clearness, the primary and secondary circles of each system represented in Figs. 4, 6, and 8 are distinguished by heavy black lines.

20. Parallels.—In every system of circles, there is a set of small circles parallel to the primary circle of the system; these small circles are called **parallels**.

21. Determination of a Point on the Celestial Sphere.—For the purpose of locating a point on the *terrestrial*

sphere, the point is referred to the equator and its secondary, the prime meridian. When the number of degrees north or south of the equator, and east or west of the prime meridian, is known, the position of the point is fully determined. The location of a point on the *celestial sphere* is determined in a similar manner; but, instead of one system, as on the terrestrial sphere, there are three systems on the celestial sphere to which any point can be referred. These systems, each named after its primary circle, are: the *horizon*, the *equinoctial*, and the *ecliptic system*.

22. Classification of Systems.—Table I shows, for each of the three systems: (1) the primary circle, (2) the secondary circles, (3) fixed secondaries that have special names, (4) the points that belong to the system and have received special names, (5) the measurements by which the position of a point is determined in that system, and (6) the parallels. The definitions and explanations of the terms are given in the succeeding articles.

HORIZON SYSTEM

23. The primary circle of the **horizon system** is the rational horizon, which has been defined as the great circle of the celestial sphere, the plane of which passes through the center of the earth perpendicular to the plumb-line at the observer's station. The zenith and nadir are the poles of the rational horizon. In Fig. 4, P is the celestial pole, Z the zenith, and $N\ VM$ the rational horizon.

24. Verticals.—Secondaries to the rational horizon are called **verticals**. Since verticals are secondaries to the rational horizon, they must all pass through the zenith and nadir and intersect the rational horizon at right angles. Verticals are also called *circles of altitude*.

25. Celestial Meridians.—Great circles passing through the celestial poles and intersecting the celestial equator at right angles are known as **celestial meridians.** They are to the celestial sphere what the meridians of longitude are to the terrestrial sphere; in fact, the meridians of

the earth extended toward the celestial sphere will mark the location of the celestial meridians. The celestial meridian most frequently used by navigators passes through the observer's *zenith*, and consequently through the north and south points of the horizon. This meridian is generally

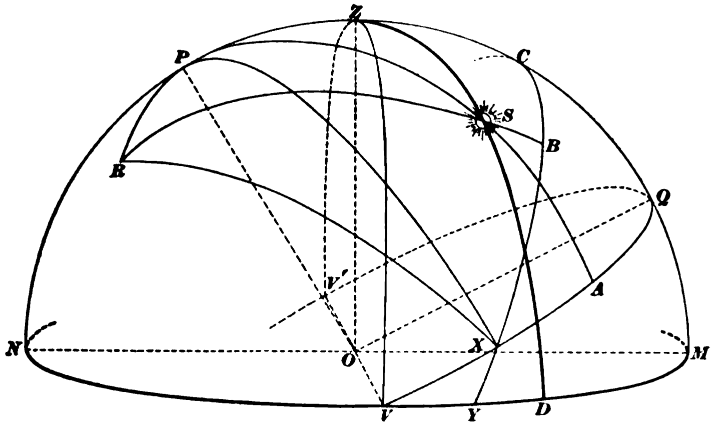


FIG. 4

known as the *observer's meridian*, or simply the *meridian;* evidently, it is also a vertical and a secondary to the horizon because it passes through the zenith. In Fig. 4, if P is the north pole, then N is the north point and M the south point of the horizon.

26. Prime Vertical.—The vertical at right angles to the observer's meridian is called the **prime vertical;** it passes through the *east* and *west* points of the horizon. In Fig. 4, which shows the primary and secondary circles of the three systems, the meridian is represented by $NPZM$ and the prime vertical by $V'ZV$.

27. True Altitude.—The **true altitude** of a celestial body is its angular distance from the rational horizon; it is measured along the vertical passing through the body, and is expressed in degrees, minutes, and seconds. Thus, the arc DS, Fig. 4, is the altitude of the body S.

28. Zenith Distance.—The **zenith distance** of a celestial body is the angular distance from the body to the zenith, and is measured along the vertical passing through the body. The zenith distance is the complement of the altitude. Thus, *SZ*, Fig. 4, is the zenith distance of the body *S*, and is the complement of the altitude *DS*.

29. True Azimuth.—The **true azimuth** of a celestial body is the arc of the horizon intercepted between the north or the south point and the vertical passing through the body. Thus, *MD*, Fig. 4, is the azimuth of the body *S*. In expressing the azimuth of a body, it is necessary to state

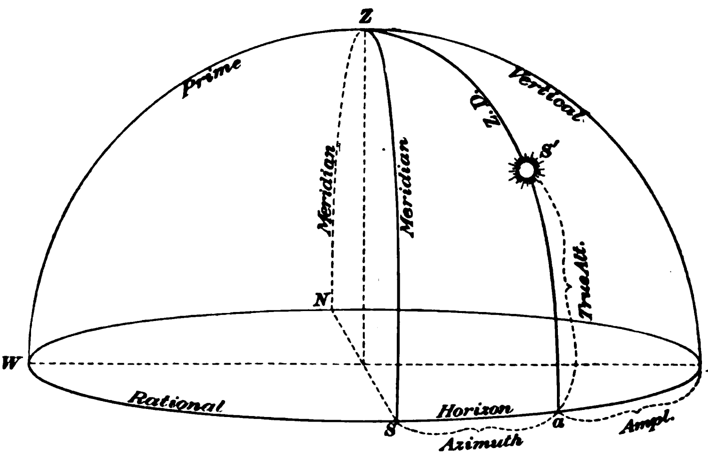


FIG. 5

whether it is measured from the north or the south point, and whether it is measured east or west. For example, if the azimuth of a body is 35°, measured from the north toward the east, it should be written N 35° E; this may also be expressed as S 145° E, since the body is 145° to the east of the south point of the horizon.

30. True Amplitude.—The **true amplitude** of a celestial body is the complement of its true azimuth; it is measured along the horizon from the prime vertical toward north or south. Thus, in Fig. 4, *VD* is the amplitude of the body *S*.

31. In the horizon system, the position of a celestial body is determined when its altitude (or its zenith distance) and its azimuth (or its amplitude) are known. This is more clearly shown in Fig. 5, which represents the horizon system of the celestial sphere divested of circles belonging to the other systems. S' is a celestial body, and the letters N, E, S, W, indicate, respectively, the north, east, south, and west points of the horizon.

EQUINOCTIAL SYSTEM

32. The primary circle of the **equinoctial system** is the celestial equator, which is the great circle in which the plane of the earth's equator intersects the celestial sphere. As stated before, the celestial equator is also called the *equinoctial circle*, or simply the *equinoctial*, because, when

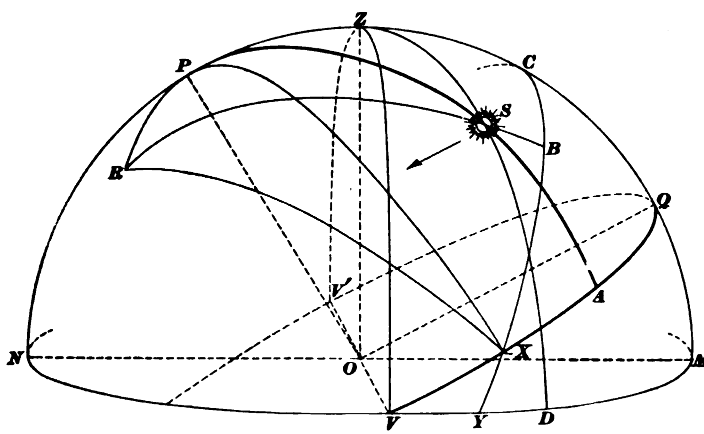


FIG. 6

the sun is in the plane of the equator, the days and nights are of equal length all over the earth.

The poles of the celestial equator coincide with those of the celestial sphere. In Fig. 6, P is the pole of the celestial sphere, and $VXQV'$ the celestial equator, or equinoctial.

33. The meridian $NPZM$, Fig. 6, is a secondary to the equator, because it passes through the pole P of the equator.

According to a previous statement, the observer's meridian is also a secondary to the horizon. Thus, the observer's meridian is a common secondary to the equator and the horizon. As stated in *Trigonometry*, the angle between two great circles is measured by the arc that they intercept on their common secondary. Therefore, the angle between the equator and the horizon is measured by the arc QM.

Again, from the fact that the pole of a great circle is everywhere at an angular distance of 90° from any part of the circle, the following conclusions are obtained. Referring to Fig. 6,

$$PQ = 90°, \text{ or } PZ + ZQ = 90°$$

and $$ZM = 90°, \text{ or } ZQ + QM = 90°$$

Therefore, $$PZ + ZQ = ZQ + QM$$

Whence, $$PZ = QM$$

That is, *the inclination of the horizon to the equator is equal to the angular distance of the zenith from the pole.*

34. Since the celestial meridians pass through the celestial poles, they are secondaries to the celestial equator. It is also evident that the planes of the celestial meridians coincide with the planes of the terrestrial meridians.

35. Diurnal Motion.—The heavenly bodies appear to rise in the east and to set in the west, making a complete revolution in the same period. This period is called a *sidereal day* and is divided into *24 sidereal hours*, each hour being subdivided into minutes and seconds. Since this apparent motion is due to the rotation of the earth on its axis, it is called the **diurnal** (daily) **motion** of the heavens.

36. Those celestial bodies which appear to move uniformly in small circles about the celestial pole, and which preserve their relative positions unchanged, are called **fixed stars,** or simply **stars.** It is not to be supposed, however, that these stars are absolutely stationary; but simply that they are so far away that any motion they may have cannot be detected by ordinary observations.

37. Hour Circles.—Let PSA, Fig. 6, be the meridian passing through a star S. Then, as the star in its apparent diurnal motion describes a small circle about the pole, the point A will move uniformly around the equator and will make a complete circuit in 24 sidereal hours. Using sidereal hours, minutes, and seconds, it is evident that A moves 360° in 24 hours. Therefore, A moves $\frac{1}{24}$ of 360° in 1 hour; or, A moves along the equator at the rate of 15° every hour. Hence, the length of any arc of the equator is equivalent to a certain period of time, the relation between the arc and the time being, as previously stated, as follows:

$$15° \text{ of arc} = 1 \text{ hour of time,}$$
$$15' \text{ of arc} = 1 \text{ minute of time,}$$
and
$$15'' \text{ of arc} = 1 \text{ second of time.}$$

For this reason, celestial meridians are also called **hour circles,** which is the more common name.

38. Hour Angle.—The angle at the pole between the observer's meridian and the hour circle passing through a celestial body is called the **hour angle** of that body.

In Fig. 6, if P is the north pole, V the west point, and V' the east point, then the star S in its diurnal motion, as indicated by the arrow, has already passed the meridian between P and Q. As the star moves from the meridian to the position S, the hour circle PSA sweeps out the hour angle QPA. The angle QPA is the angle between the two great circles PZQ and PSA, and is measured by the arc QA. Thus, the time that has elapsed since the star was on the meridian is measured by the hour angle QPA, or by the arc QA converted into time at the rate of 15° to the hour.

NOTE.—Arts. **37** and **38** are very important in nautical astronomy; hence a clear grasp of their contents is essential.

39. Equinoxes.—The points where the ecliptic intersects the celestial equator are called the **equinoctial points,** or the **equinoxes.** The point where the sun crosses the celestial equator in passing from the southern to the northern hemisphere is called the *vernal*, or *spring*, *equinox;* the point where the sun crosses the equator in passing from the

northern to the southern hemisphere is called the *autumnal*, or *fall, equinox*. Fig. 3 shows very clearly the position of the equinoxes. They are situated diametrically opposite each other at the intersection of the great circles representing the ecliptic and the celestial equator.

Strictly speaking, the equinoxes are not the points, but are the times when the sun is at the equinoctial points. The vernal equinox occurs about March 21, and the autumnal equinox, about September 21.

40. Solstices.—The points of the ecliptic that are 90° distant from the equinoxes are called the **solstitial points**, or the **solstices**; because at these points, Q and Q', Fig. 3, the sun stands, or stops moving northwards or southwards from the equator.

The solstices are more correctly defined not as points, but as the times when the sun is at the solstitial points. The summer solstice occurs about June 21, and the winter solstice about December 21.

41. Equinoctial and Solstitial Colures.—The **equinoctial colure** is the meridian passing through the equinoxes. The **solstitial colure** is the meridian passing through the solstices; this colure is a common secondary to the ecliptic and equator.

42. Right Ascension.—The arc of the celestial equator measured *eastwards* from the vernal equinox to the hour circle passing through a celestial body is called the **right ascension** of that body; it is reckoned in hours, minutes, and seconds, and, since the equator is divided into 24 hours, right ascension may be of any value from 0 to 24 hours. In Fig. 6, XA is the right ascension of the body S. The term right ascension is usually denoted by the letters R. A.

43. Declination.—The angular distance of a body north or south of the celestial equator is called **declination.** Declination is measured by the arc of the hour circle passing through the object and intercepted between it and the equator. Thus AS, Fig. 6, is the declination of the body S. The

declination of a heavenly body is *north* if the body is north of the equator, and *south* if the body is south of the equator.

44. Polar Distance.—The angular distance of a celestial body from the nearer pole is known as the **polar distance**; it is measured by the arc of the hour circle intercepted between the pole and the body. The polar distance is therefore the complement of the declination. Thus, if the declination of the sun is 15° 30′ N, its polar distance is 90° − 15° 30′ = 74° 30′; or, its distance from the north celestial pole is $74\frac{1}{2}$°.

45. Parallels of declination are small circles parallel to the celestial equator.

46. In the equinoctial system, the position of a star is determined by its hour angle and polar distance, or by its right ascension and declination. This is clearly indicated in Fig. 7, which shows the different elements of the system.

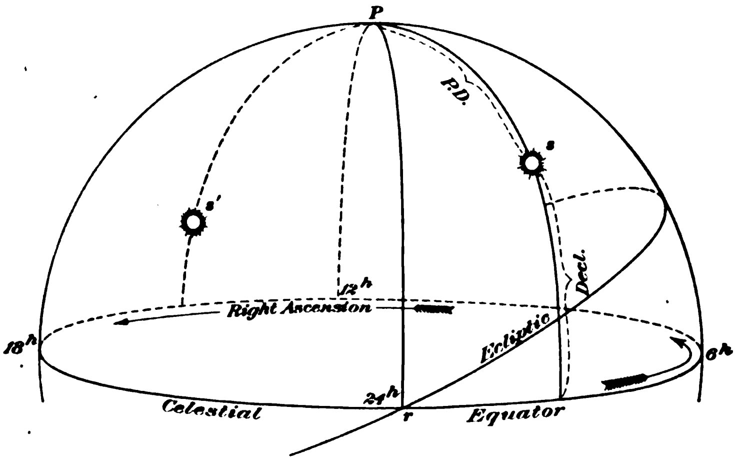


FIG. 7

The letters *s* and *s′* represent two celestial bodies, and *r* the vernal equinox. Hence, the right ascension of the celestial body *s* is about 3 hours, while that of *s′* is about 15 hours.

The right ascension of a point on the celestial sphere corresponds exactly with the longitude of a place on the

terrestrial sphere. Right ascension is reckoned from the vernal equinox, just as terrestrial longitude is reckoned from the Greenwich meridian. The declination of a point on the celestial sphere corresponds with the latitude of a place on the terrestrial sphere, and declination parallels correspond with parallels of latitude.

ECLIPTIC SYSTEM

47. The primary circle of the **ecliptic system** is the ecliptic, part of which is represented in Fig. 8 by the arc YBC. The angle between the ecliptic and the celestial equator is called the *obliquity of the ecliptic*, and is about

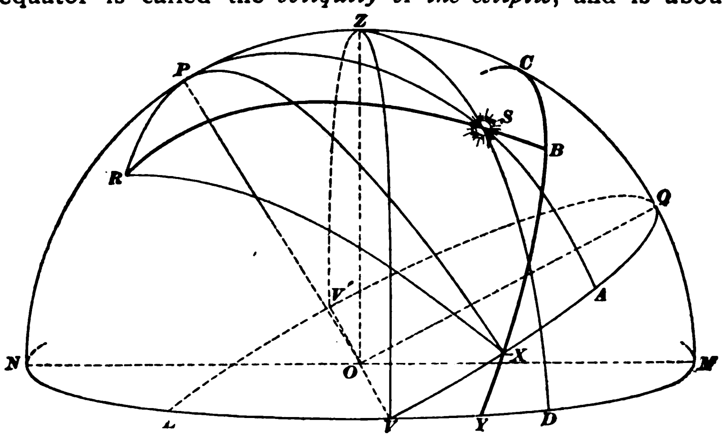


Fig. 8

23° 27′. The plane of the ecliptic coincides with the plane of the earth's orbit, and the plane of the celestial equator is the same as the plane of the terrestrial equator. Hence, the obliquity of the ecliptic is equal to the inclination of the earth's orbit toward the earth's equator.

48. The angle between two great circles is measured by the arc that they intercept on their common secondary, and since the solstitial colure is a common secondary to the ecliptic and the equator, it follows that the obliquity of the ecliptic is measured by the arc of the solstitial colure intercepted between the ecliptic and the equator. At the

summer solstice, the sun stops moving northwards from the equator and begins to move southwards toward the equator. Therefore, at the summer solstice, the sun has attained its greatest distance north of the equator; that is, the sun's northerly declination is then greatest. At the winter solstice, the sun's southerly declination is greatest. At the solstices, the sun's declination is measured by the arc of the solstitial colure intercepted between the ecliptic and the equator; and therefore, the sun's declination at the solstices is equal to the obliquity of the ecliptic. In other words, the sun's maximum declination is equal to the obliquity of the ecliptic.

49. Secondaries to the ecliptic are called **circles of celestial longitude.**

50. Celestial Latitude and Longitude.—The **celestial latitude** of a star is its angular distance from the ecliptic measured along the circle of longitude that passes through the star.

The **celestial longitude** of a star is the arc of the ecliptic measured eastwards from the vernal equinox to the circle of longitude passing through the star.

In Fig. 8, XB is the celestial longitude and BS is the celestial latitude of the star S. In this system, therefore, the position of a celestial body is fixed by its celestial latitude and longitude.

COMPARISON OF THE THREE SYSTEMS

51. The altitude and the azimuth of a star serve to fix its position relative to the horizon; but owing to diurnal motion they are constantly changing. The polar distance and hour angle fix the position of a star relative to the equator. The advantages of this system are that, for fixed stars, the polar distance is constant and that the hour angle increases at a uniform rate.

Since the vernal equinox and the equator have the same diurnal motion as the stars, the right ascension and the declination of a fixed star are almost invariable. For this reason, right ascension and declination afford a convenient

method of marking the relative positions of the stars on the celestial sphere. The celestial latitude and longitude of a star are unaffected by diurnal rotation. The sun is always in the ecliptic, and the moon and planets are always very near to it. Hence, celestial latitude and longitude are very convenient for tracing the paths of the sun, moon, and planets.

Celestial longitude differs from right ascension in that it is measured on the ecliptic instead of on the equator, and in that it is not measured in time, but in degrees, minutes, and seconds from 0° to 360°. Since the invention of the pendulum clock and the chronometer, however, the equinoctial system has been found more convenient than the ecliptic system, because right ascension can at once be expressed in time. The ecliptic system is never used in navigation, but some knowledge of it may prove useful to the navigator.

52. Having explained the systems of circles by which to record and compare the observed positions of the heavenly bodies, a brief account will now be given of the solar system and the positions and movements of the principal celestial bodies used for navigational purposes.

SOLAR SYSTEM AND THE UNIVERSE

SOLAR SYSTEM

53. A body, like the earth, that makes a circuit about the sun is called a **planet.** A smaller body, like the moon, that revolves about a planet is called a **satellite** of that planet. The sun, planets, and satellites constitute what is called the **solar system.** When viewed through a telescope, a planet shows a circular disk like that presented to the naked eye by the moon. The fixed stars, except the sun, are so far away that even in the most powerful telescopes they present no disk, but appear merely as a twinkling, bright point. A fixed star, when viewed through a telescope, appears brighter, but not larger, than when viewed with the naked eye.

54. When one body revolves about another, the path of the revolving body is called its **orbit.** The line joining the center of the revolving body to the center of the body about which it revolves is called the **radius vector.** The time

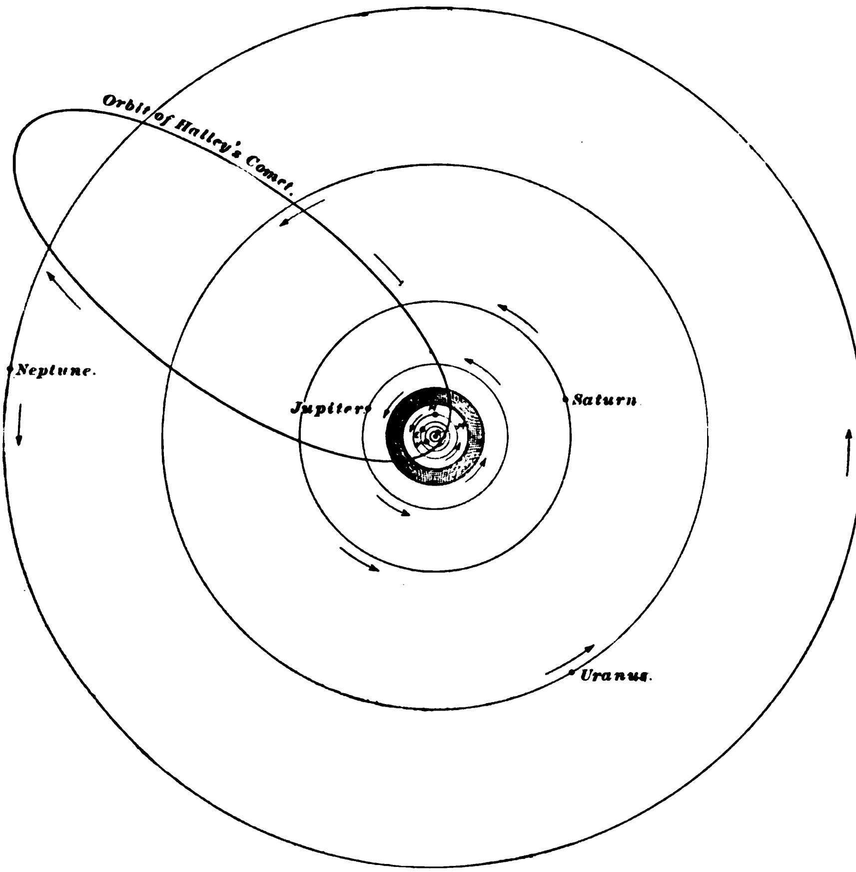


FIG. 9

occupied by a revolving body in making a complete revolution is called its **periodic time.**

55. Inferior and Superior Planets.—Including the earth, there are eight known planets, which are divided into two classes: *inferior planets* and *superior planets.*

Inferior planets are those whose orbits lie within that of the earth (see Fig. 9); **superior planets** are those whose orbits are greater than that of the earth, and, consequently, lie outside of it. When the planets themselves are considered and not their orbits, they fall into two divisions: *major planets* and *minor planets*. Commencing from the sun, the planets appear in the following order:

Minor	Mercury	Interior, or inferior
	Venus	
	The Earth	
	Mars	Exterior, or superior
Major	Jupiter	
	Saturn	
	Uranus	
	Neptune	

56. Asteroids.—Between the orbits of Mars and Jupiter there are a number of small planets, called **asteroids**. At present about 300 asteroids are known; they are supposed to be the fragments of a burst planet.

57. Movements of Planets.—All the planets move around the sun in the same direction; namely, opposite to that in which the hands of a watch move (see Fig. 9). Those nearest the sun move more rapidly than those that are farther away.

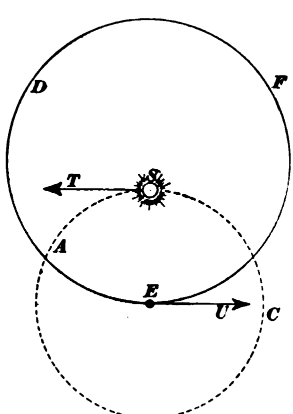


FIG. 10

58. The motion of the sun, which the ancients believed to be real, is only apparent, and is due to the motion of the earth in its orbit about the sun.

Let S, Fig. 10, represent the sun and E the earth. Let $A\ B\ C$ be the annual path that the sun appears to describe about the earth. In this figure the north pole is supposed to be above the plane of the paper. When the sun is at S, it appears to be moving in the

direction $S\,T$ in relation to surrounding stars. Hence, the sun appears to describe its path in the direction $A\,B\,C$; that is, counter-clockwise. Since this apparent motion of the sun is due to the real motion of the earth, when the sun is at S and the earth at E, the earth must be moving in the direction $E\,U$; hence, the earth describes its orbit in the direction $D\,E\,F$, that is, counter-clockwise. Thus, the real motion of the earth about the sun takes place in the same direction as the apparent motion of the sun about the earth.

NOTE.—The apparent motion of the sun just referred to should not be confounded with the diurnal, or daily, motion of the sun, which is due entirely to the rotation of the earth on its axis. The apparent motion of the sun produced by the latter cause takes place in the direction of the hands of a watch, or from east to west; to observe the annual motion of the earth, special instruments are necessary.

59. Besides their revolution around the sun, each of the planets turns on its axis in the same manner as does the earth. This form of movement, referred to in the preceding note, is termed *rotation*. The sun itself has a rotary motion about its axis, the period of rotation being estimated at about 25 days.

60. Kepler's Laws.—The laws relating to the movements of the planets about the sun, named **Kepler's laws,** in honor of their discoverer, John Kepler,* are as follows:

I. *The orbit of each planet is an ellipse that has the sun in one of its foci.*

II. *The radius vector joining the sun to the planet sweeps over equal areas in equal times.*

III. *The squares of the periodic times of the several planets vary as the cubes of their mean distances from the sun.*

In order that the meaning and importance of these laws may be fully understood, each will be explained in the simplest manner possible.

61. First Law.—An ellipse can be conveniently constructed in the following manner: Tie the ends of a piece of

---

***Johann Kepler*, German astronomer, physicist, and mathematician, born in Wurtemburg, 1571, died 1630.

fine, inextensible string together so as to form a loop; then place the loop over two pins fixed at the points S and S', Fig. 11, and place the point of a pencil in the loop. Now move the pencil so as to keep the string always stretched, and the curve described by the pencil will be an ellipse. Produce the line $S'S$ to meet the curve in the points A' and A, bisect $S'S$ at C, and through C draw a perpendicular to $S'S$, intersecting the curve in the points B and B'. Then, $A'A$ will be the *major axis*, and BB' the *minor axis* of the ellipse; and the points S and S' will be the *foci* of the ellipse. The shape of the ellipse depends on the distance of S from C, and this distance expressed with CA as unity $\left(= \frac{CS}{CA}\right)$ is called the **eccentricity** of the ellipse.

According to Kepler's first law, the orbits of the several

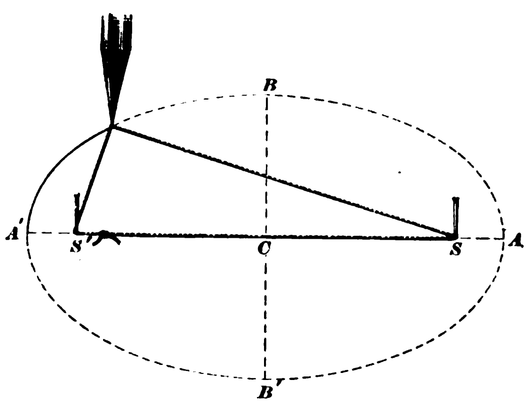


FIG. 11

planets are ellipses similar to the one represented in Fig. 11, although the eccentricity is very small, thus making them nearly circular. In the case of the earth's orbit, the eccentricity is about $\frac{1}{60}$; that is, the distance CS is only $\frac{1}{60}$ part of CA.

62. If the ellipse in Fig. 11 represents the orbit of a planet, S being the focus occupied by the sun, the point A' where the planet is at its greatest distance from the sun is called **aphelion,** and the point A where the planet is nearest

the sun is called **perihelion.** The line *A′A* is the major axis of the ellipse, and the line obtained by producing *A′A* indefinitely in both directions is called the **line of apsides;** thus, the major axis of the ellipse is a limited portion of the line of apsides.

63. Second Law.—Let the ellipse *ABCDE*, Fig. 12, represent a planet's orbit having the sun at the focus *S*. Suppose the time occupied by the planet in passing from *B* to *C* is equal to the interval in moving from *D* to *E*. It is found by observation that the distances *BC* and *DE* are not equal; that is, the planet does not move with the same velocity in all parts of its orbit. From the observations of Tycho Brahe,* Kepler found that the area of the sector *SBC* is equal to that of the sector *SDE*; that is, the area swept over by the radius vector while the planet moves from *B* to *C* is equal to the area swept over by the radius vector while the planet moves from *D* to *E*, provided the time from *B* to *C* is equal to the time from *D* to *E*. This explains Kepler's second law.

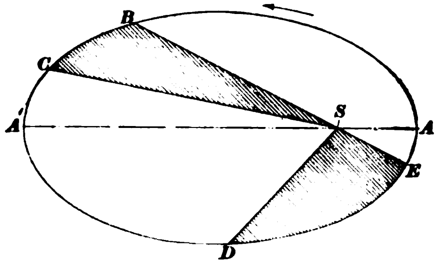


FIG. 12

By examining Fig. 12, the following important fact can be readily deduced from Kepler's second law: *A planet moves faster in that part of its orbit where it is nearer the sun than in that part of its orbit where it is more remote.* Thus, the earth moves faster in winter than in summer.

64. Third Law.—Let P_1 and P_2 be two planets, and let

D_1 = mean distance of P_1 from the sun;
D_2 = mean distance of P_2 from the sun;
T_1 = periodic time of P_1;
T_2 = periodic time of P_2.

* Danish astronomer, born 1546, died 1602.

Then, Kepler's third law is expressed by the equation

$$\frac{T_1^2}{T_2^2} = \frac{D_1^3}{D_2^3}$$

From this law the approximate mean distance of any planet from the sun can be found when the periodic time is known; or, if the mean distance is known, its periodic time may be obtained.

EXAMPLE.—The mean distance of the earth from the sun is approximately 92,000,000 miles. The periodic time of the planet Jupiter is nearly 12 years. Find, approximately, the mean distance of the planet Jupiter from the sun.

SOLUTION.—Let P_1 be the earth, and P_2 Jupiter. Then, using 1,000,000 mi. as a unit of length and 1 yr. as a unit of time, we have $D_1 = 92$, $T_1 = 1$, and $T_2 = 12$. Substituting these values in the equation

$$\frac{T_1^2}{T_2^2} = \frac{D_1^3}{D_2^3},$$

we get

$$\frac{1^2}{12^2} = \frac{92^3}{D_2^3}$$

Solving, $D_2^3 = 12^2 \times 92^3 = 144 \times 92^3$. Therefore,

$$D_2 = \sqrt[3]{144} \times 92 = 5.24 \times 92, \text{ nearly,}$$

or $D_2 = 482$, nearly. Thus, Jupiter's mean distance from the sun is 482,000,000 mi. Ans.

65. Movement of Planets.—In Fig. 13, let the outside circle represent the orbit of a superior planet, the solid circle the orbit of the earth, the dotted circle that of an inferior planet, and S the sun. Assume, also, that the earth is situated at E.

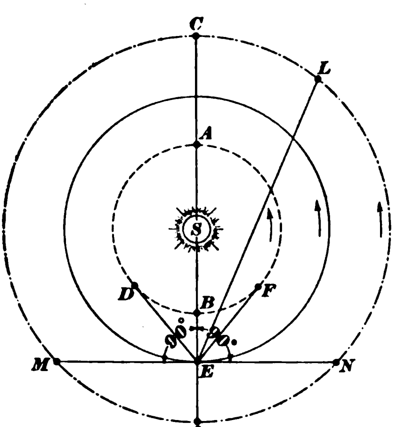


FIG. 13

When a planet appears to be close to the sun, it is in **conjunction.** A superior planet is then at C, or beyond the sun, while an inferior planet is at either A or B. If the planet is at A, it is a **superior conjunction,** and if at B, it is an **inferior conjunction.**

When a planet is at O, directly opposite the sun, it is said to be in **opposition.**

The **elongation** of a planet is the angle formed by lines drawn from the earth to the sun and to the planet. The greatest elongation of an inferior planet occurs when the planet is at D or at F. The elongation of a superior planet when at L is the angle SEL.

When the elongation of a superior planet is 90° (at either M or N) the planet is in **quadrature.**

66. Apparent Motion.—The apparent motions of the planets are very irregular; generally, they seem to move

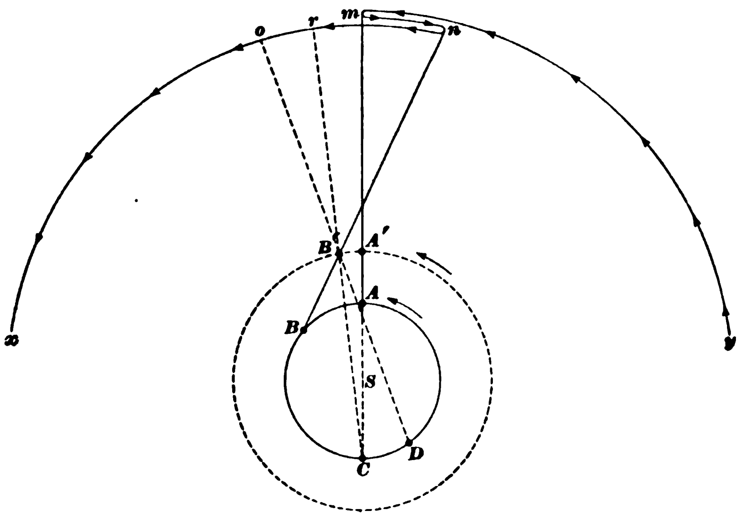


FIG. 14

from west to east, but at times they move in the opposite direction. The cause of the irregularity of the apparent motion of a planet can be easily explained. For this purpose, it is convenient to assume that the planets move in the plane of the ecliptic.

In Fig. 14, the earth's orbit is represented by the solid circle, and that of the planet Mars by the dotted circle. The curve xy is the ecliptic, and the north pole of the celestial

sphere is above the plane of the paper. If a watch with its face upwards is laid on the paper, the planets revolve about the sun S in the direction opposite to the motion of the hands of the watch. At the time when Mars is in opposition, the earth is at A, and Mars is at A'. To an observer on the earth, Mars then appears on the celestial sphere at m. After a short interval, the earth has moved to B, and Mars has moved to B'. The observer then sees Mars in the direction $B B'$, and, consequently, Mars appears on the celestial sphere at n. During this interval the real motion of Mars has been forwards from A' to B', yet its apparent motion has been backwards from m to n. This apparent backward motion of the planet is called a *retrograde motion*.

The retrograde motion of a planet is most rapid when it is in opposition, and becomes gradually slower as the interval from the time of opposition increases. At a certain time the retrograde motion ceases, and the planet maintains for a short time the same position relatively to the earth; the planet is then said to be *stationary*. The position of the stationary point depends on the relative sizes of the orbits of the earth and the planet. After the stationary point is passed, the apparent motion of the planet becomes direct.

When a planet is in superior conjunction, its apparent motion is most rapid and is direct. Suppose, for example, that Mars is at A' when the earth is at C. Mars then appears on the celestial sphere at m. After a short interval, the earth has moved to D and Mars has moved to B'. An observer then sees the planet in the direction $D B'$, and, consequently, Mars appears on the celestial sphere at o; hence, the apparent motion of Mars during this interval is $m o$. But if the earth had remained motionless at C, the planet would be observed in the direction $C B'$, and would appear on the celestial sphere at r; then, the apparent motion of Mars would be $m r$. Thus, at superior conjunction, the apparent motion of a planet is direct and is greater than the planet's real motion. The direct apparent motion of a planet becomes more and more rapid from the stationary point to the point

of superior conjunction; then, the rapidity of its direct motion diminishes until it again becomes stationary.

67. Sidereal and Synodic Periods.—The **sidereal period** of a planet is the time required by the planet to make a complete revolution around the sun from a star to the same star again, *as seen from the sun.*

The **synodic period** of a planet is the time between two successive conjunctions of the planet and the sun, *as seen from the earth.*

The relation between the sidereal and synodic periods is expressed by the formula

$$\frac{1}{S} = \frac{1}{p} - \frac{1}{e},$$

in which S denotes the synodic period of the planet, and p and e denote, respectively, the sidereal period of the planet and the earth.

If p is larger than e, as in the case of the superior planets, the relation is then written

$$\frac{1}{s} = \frac{1}{e} - \frac{1}{p}$$

For example, Mercury's sidereal period is 88 days; therefore,

$$\frac{1}{S} = \frac{1}{88} - \frac{1}{365\frac{1}{4}} = \frac{277\frac{1}{4}}{32,142}$$

Whence, $$S = \frac{32,142}{277\frac{1}{4}} = 116$$

Therefore, Mercury's synodic period is 116 days.

68. Elements of Solar System.—Table II will serve to illustrate the chief elements and relative sizes of the principal members of the solar system.

69. Each of the superior planets is attended by one or more moons similar to that of the earth. These moons move around the planets in the same direction that the planets themselves revolve around the sun. The only exceptions are found in the satellites of Uranus and Neptune, which revolve in the opposite direction.

TABLE II

PRINCIPAL ELEMENTS OF THE SOLAR SYSTEM

Name	Diameter (Diameter of the Earth as Unity)	Sidereal Period (Period of the Earth as Unity)	Period of Rotation	Mean Distance From the Sun (Distance of the Earth as Unity)	Volume (Volume of the Earth as Unity)	Eccentricity of Orbit
Mercury . . .	.373	.241	88 days (?)	.39	.05	.2056
Venus	.999	.615	225 days(?)	.72	.98	.0068
The Earth . .	1.000	1.000	$23^h\ 56^m\ 4^s$	1.00	1.00	.0168
Mars	.528	1.881	$24^h\ 37^m\ 23^s$	1.52	.15	.0933
Jupiter	11.061	11.862	$9^h\ 55^m\ 37^s$	5.20	1,279.41	.0483
Saturn	9.299	29.457	$10^h\ 14^m\ 24^s$	9.54	718.88	.0561
Uranus	4.234	84.020	Unknown	19.18	69.24	.0463
Neptune . . .	3.798	164.767	Unknown	30.06	54.96	.0090
The Sun . . .	108.558	—	$25^d\ 4^h\ 29^m$	—	1,283,720	—
The Moon . .	.273	—	$27^d\ 7^h\ 43^m\ 11^s$	—	.0204	.0549

THE EARTH

70. Motions of the Earth.—In a previous article it was stated that the apparent diurnal motion of the heavens is due to the earth's rotation. This rotation causes the phenomena of day and night.

The annual motion of the earth in its orbit about the sun has already been described. This motion determines the length of the year and produces the phenomena of the seasons.

71. The Seasons.—The earth, in its travel around the sun, always keeps its axis nearly parallel to itself. The axis is inclined to the plane of the orbit at an angle of 23° 27′.

The position of the earth on March 21, which also corresponds to the time of the vernal equinox, is represented by the lower figure in Fig. 15. At this time, the boundary circle of the illuminated portion of the earth passes through the two poles, with the result that day and night are equal all over the globe. As the earth advances in its orbit, the north pole is gradually turned more and more toward the

sun S, while the south pole is turned away. This process continues until June 21; this is the time of the summer solstice, when the north pole is turned as much as possible toward the sun, and the south pole is turned away from the sun. The result is that everywhere in the northern hemisphere the days are long, while in the southern hemisphere they are short. As the earth continues its revolution, the north pole gradually turns away from the sun, while the south pole turns toward it; and when the time of the autumnal equinox is reached, September 21, day and night are equal everywhere. After passing that point, the north pole continues to turn away from the sun, and at the time of the

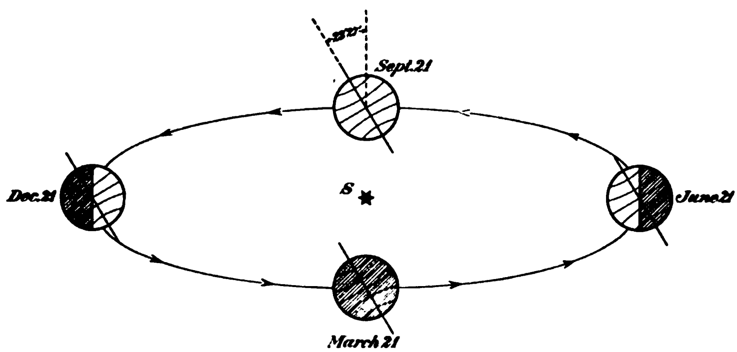


FIG. 15

winter solstice, December 21, the days everywhere in the northern hemisphere are short, while the southern hemisphere, on the other hand, is enjoying long summer days.

At the equator, night and day are of equal length the whole year round, and seasons, in the proper sense of the word, do not exist. If a small circle parallel to the equator were drawn at a distance of 23° 27′ from each pole, it would form the boundary of the region of perpetual day and night at those places. On account of the eccentricity of the earth's orbit, the lengths of the different seasons are unequal. During spring and summer of the northern hemisphere, the earth is in that portion of its path where it moves less rapidly; and during autumn and winter it moves with

greater velocity. Hence, spring and summer are of longer duration than autumn and winter. The difference is not considerable; still it is sufficient to be appreciable.

72. Velocity of Rotation.—The rotation of the earth causes different points on the earth's surface to move with different velocities, the velocity of any point being determined by its latitude. A point on the equator moves around the equator, the length of which is about 25,000 miles, in 24 hours; this is equivalent to a velocity of about 17 miles per minute. A point in the latitude of London, England, moves at the rate of 11 miles per minute; and a point at either of the poles has no motion due to the earth's rotation.

73. Precession and Nutation.—The equinoctial points have a slow, retrograde motion along the ecliptic; in other words, they are gradually moving toward the sun. As a consequence, the equinoxes occur at shorter intervals than they otherwise would. This phenomenon is called the **precession of the equinoxes.**

If the earth were a perfect sphere, its axis would constantly preserve the same direction and there would be no such thing as precession. However, the attraction of the sun and the moon on the bulging matter at the equator causes the earth's axis to have a slow, conical motion; therefore, the pole of the equator describes a small circle about the pole of the ecliptic, completing the circle in a period of 25,868 years.

A result of the precession of the equinoxes is the apparent annual change of position of all the stars in the heaven, returning to the same point only at the close of this great secular cycle. The explanation of this remarkable motion is due to the genius of the immortal Newton.*

By precession alone, the axis of the earth would move in the circumference of a circle *a b*, Fig. 16, about the pole *p* of the ecliptic. This motion, however, is modified by the unequal influence of the moon on the equatorial parts of the

***Sir Isaac Newton*, eminent English astronomer, physicist, and mathematician; born in Woolsthorpe, 1642; died 1727.

earth, producing a vibration of about 9″ on each side of the circumference. Thus, the line described by the pole as it advances is a delicate wave lying along the arc *a b*. This vibratory motion is called **nutation**, or *nodding;* the time required by the pole to describe one of these waves is 18 years and 8 months. The waves in the figure are, of course, greatly exaggerated. Represented in their true form, they would be small enough to cross the arc about 700 times.

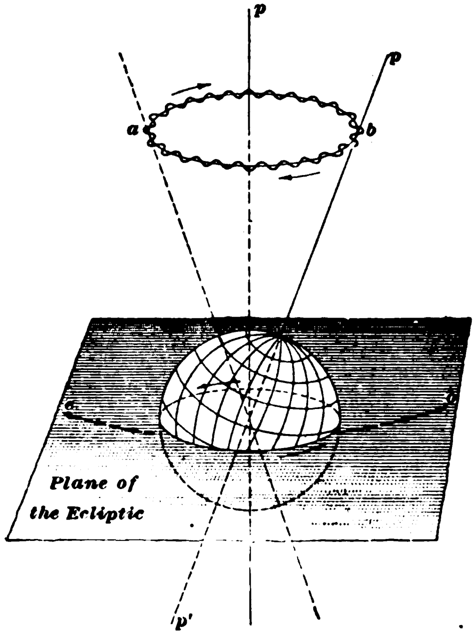


FIG. 16

74. First Point of Aries.—The earliest astronomers whose records have been preserved placed the vernal equinoctial point in the constellation Aries instead of in the constellation Pisces, where it now is; consequently, they called the vernal equinoctial point the **first point of Aries,** and it still retains this name. The expression, the sun enters Aries—which is often found in almanacs—means that the sun passes through the vernal equinoctial point.

THE MOON

75. The average distance of the moon from the center of the earth is about 60.3 times the earth's equatorial radius, or 238,840 miles. The moon's orbit, like the earth's, is an ellipse, the earth being one of its foci. The size of the moon is only $\frac{1}{49}$ that of the earth, yet its influence on the ocean and

the atmosphere is comparable with that of the sun, and perhaps, to a certain degree, is even more important in regard to the production of tides.

76. Sidereal and Synodic Month.—The revolution of the moon around the earth in relation to the *stars* takes place in 27 days, 7 hours, and 43 minutes. This period is called a **sidereal month.** During this time, however, the earth has not been motionless, and, consequently, the sun appears to have advanced a certain distance. The moon requires about 2 days more to make up this distance and to return to the same point in relation to the *sun.* This period is called a **synodic month;** its average length is 29 days, 12 hours, 44 minutes, and 2.9 seconds.

77. Nodes of the Moon.—The inclination of the moon's orbit toward the plane of the ecliptic is somewhat more than 5°, and the points where the orbit crosses the circle of the ecliptic are called the **moon's nodes.** The point where the moon passes the ecliptic from the south to the north side is called the **ascending node;** and the point where the moon passes from north to south of the ecliptic is called the **descending node.** These nodes, however, are in constant motion—sliding westwards on the ecliptic, like the vernal equinox, and completing their revolution in $18\frac{1}{2}$ years.

78. Rotation and Libration of the Moon.—The moon rotates on its own axis in the same period in which it makes a revolution about the earth. Since the axis of the moon is very nearly perpendicular to the line joining the center of the moon to the center of the earth, the result of the moon's rotation is that the same face of the moon is presented to the earth at all times. The moon accomplishes this feat in the same manner as when a man walks around a pole with his face turned toward it. Although the moon always presents the same face to the earth, yet, on account of the slight inclination of the moon's axis to its orbit, certain regions near the edge become alternately more or less visible. This phenomenon is called **libration.**

PHASES OF THE MOON

79. The moon is not a self-luminous body; and the light coming from it—moonlight—is simply reflected sunlight. The various forms of the visible portion of the moon's illuminated surface are called **phases**, and are caused by the moon's continual change of position in relation to the sun

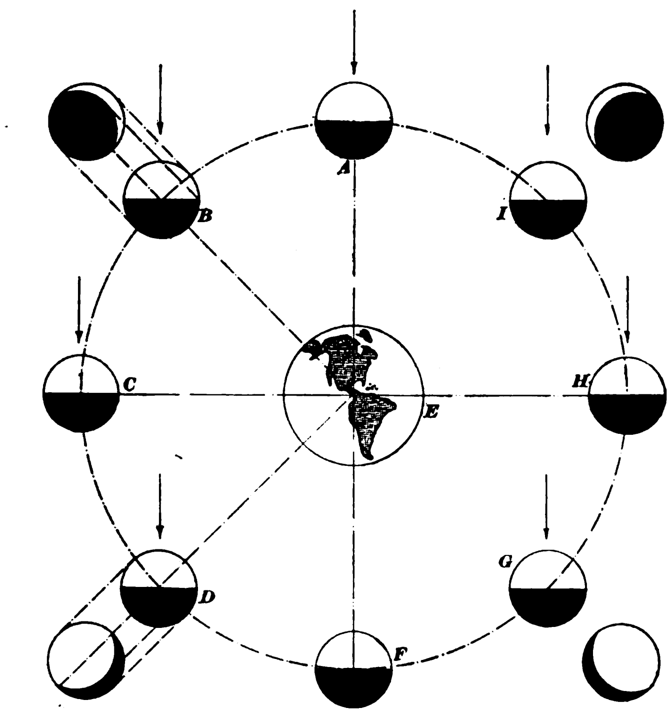


FIG. 17

and the earth. Fig. 17 shows the various phases of the moon, the direction of the sun's rays being indicated by arrows.

When at A, the moon is in conjunction, and her dark side is turned toward the earth, thus rendering her wholly invisible; this is called *new moon*. At B the illuminated part commences to be visible, and at C half of her illuminated

hemisphere is seen; this phase is called the *first quarter.* When the moon is at F, she is in opposition, and the whole of her illuminated surface is turned toward the earth; this is called *full moon.* From F to A the phases are repeated in reverse order, H being the *last quarter.* When less than half of the illuminated part is visible, it is called the *crescent phase*, and when more than half is visible, it is called the *gibbous phase.*

ECLIPSES OF THE MOON AND SUN

80. The moon is **eclipsed** when it is obscured wholly or in part by the earth's shadow. This can only occur at opposition, or full moon. An eclipse of the sun occurs when the moon comes between it and the earth; this can happen only at conjunction, or new moon. There are two kinds of lunar eclipses: *partial* and *total.*

An eclipse is **partial** when only a portion of the moon enters into the shadow, and it is **total** when she passes completely into the shadow. Before going further the shape of

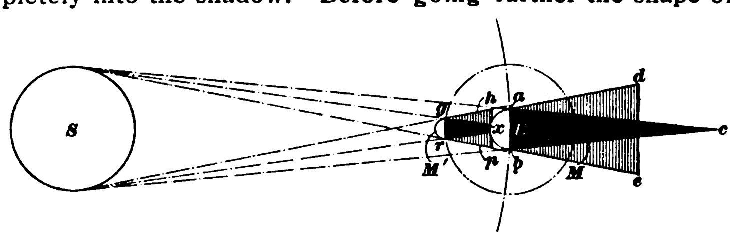


FIG. 18

the shadow cast by the earth and the moon, respectively, will be considered.

In Fig. 18, S represents the sun, E the earth, M' the moon at conjunction, and M the moon at opposition. The darkly shaded conical portion $a\,b\,c$ of the earth's shadow is called the **umbra.** The lightly shaded portions $d\,a\,c$ and $e\,b\,c$, bounded by tangents drawn across the opposite sides of the earth and sun, are called the **penumbra** of the shadow. When the moon is at M', or in conjunction, the dark space enclosed by $g\,x\,r$ is the umbra, and portions $h\,g\,x$ and $n\,r\,x$ the penumbra of the moon's shadow. Eclipses of the moon

are caused, as mentioned before, by the earth passing between her and the sun. If the orbit of the moon were in the same plane as the ecliptic, a lunar eclipse would occur every month. However, her orbit is inclined to the ecliptic, and as a result lunar eclipses are not frequent—seldom more than two in a year. An eclipse of the moon is possible only when opposition happens near the line of nodes, so that some part of the three bodies lies in a straight line. At other times, the moon passes north or south of the shadow without even touching it. A lunar eclipse can never occur when the moon's celestial latitude exceeds 63′. In order that an eclipse of the sun may occur, the moon's celestial latitude must be less than 94′, otherwise the moon's shadow will pass either over the earth or under it. Solar eclipses are

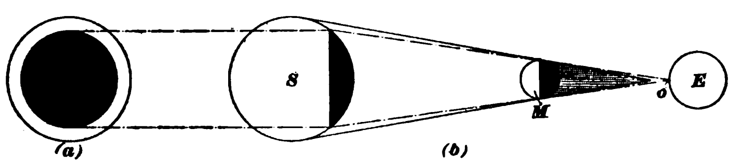


FIG. 19

consequently more frequent than lunar eclipses. A solar eclipse, however, is visible only from a small portion of the earth, while an eclipse of the moon can be seen over more than half the earth; hence, the number of lunar eclipses visible at any place exceeds the number of solar eclipses visible at that place. In a period of 18 years, 70 eclipses are possible, of which 41 are solar and 29 lunar. The greatest number of eclipses in a year is 7, and the smallest number is 2.

81. When the umbra $g\,x\,r$, Fig. 18, of the moon's shadow is not long enough to reach the earth, which occurs when the moon's angular semi-diameter is less than that of the sun, the eclipse is called **annular.**

The annular eclipse is illustrated in Fig. 19. To an observer at o the moon will appear smaller than the sun, and the effect will be as shown in (a). The whole disk of the sun is observed except a narrow ring around the outside encircling the darkened center.

THE STARS

82. Constellations.—Stars are divided into groups in the same manner as a state is divided into counties. These groups, called **constellations,** have been recognized from prehistoric times, and have received fanciful names. Sometimes the arrangement of the stars bears a resemblance to the object after which the constellation is named; in general, however, no reason can be given for the way in which the stars have been grouped and named.

83. The Zodiac.—A zone 16° wide, 8° on each side of the ecliptic, is called the **zodiac.** The name is derived from a Greek word that means *a living creature*, and was suggested by the fact that, with one exception, the constellations in this zone form figures of living animals. The ancient astronomers made the zodiac of this particular width because the moon and the planets known at that time never receded more than 8° from the ecliptic.

84. Signs of the Zodiac.—The length of the zodiac is divided into twelve parts of 30° each. These twelve parts are called the **signs of the zodiac** and are named after the constellations that occupy them. The names of the signs of the zodiac are: Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius, and Pisces (see Map of Principal Stars and Constellations).

On the star map just referred to, it will be seen that the vernal equinoctial point ♈ is situated in the constellation Pisces, and that the autumnal equinoctial point ♎ is situated in the constellation Virgo. The direction of the sun's annual motion in the ecliptic is indicated by the arrow.

85. Classification of Stars.—Besides the divisions already mentioned, the stars are also classified according to their brightness. Twenty of the brightest stars in the sky are called stars of the *first magnitude;* a number of stars that are a little less bright than these are said to be of the *second magnitude;* and so on. The faintest stars visible to the naked

eye are of the *sixth magnitude*. The same system of classification has been extended to telescopic stars. The 40-inch Yerkes telescope of the University of Chicago reveals stars of the seventeenth magnitude.

It must be carefully borne in mind that the magnitude of a star has nothing whatever to do with the real or apparent size. Even in the most powerful telescope, a star shows no sensible disk; the telescope does not make a star appear larger, but only makes it brighter by collecting more of its light.

The stars of the first magnitude are the fewest in number; and the smaller the magnitude, the larger is the number of stars included in it, as shown in the following list:

	Number of Stars
First magnitude	20
Second magnitude	59
Third magnitude	182
Fourth magnitude	530
Fifth magnitude	1,600
Sixth magnitude	4,800

According to this estimation, the number of stars visible to the ordinary eye is about 7,000. With the aid of a common marine glass, however, the number increases to at least 100,000, and a 2½-inch telescope brings out about 300,000. A telescope 36 inches in diameter increases the number enormously, probably revealing about 100,000,000.

86. Light-Year.—When measuring the distance of a star, the earth's diameter, and even the diameter of the earth's orbit, is too small to be a convenient unit. The distances are altogether too enormous; therefore, the *light-year* is the unit generally employed in computing the distance of a star. By **light-year** is meant the distance over which light travels in 1 year. Thus, when a star's distance is said to be 9 light-years, it means that the star's light, traveling at the rate of nearly 186,000 miles per second, requires 9 years to reach the earth. Of the stars whose distances have been determined, the nearest to the earth is Alpha Centauri; its light requires

more than 4 years to reach the earth. The light of Sirius, a star of the first magnitude, requires about 8 years to traverse the distance to the earth.

Table III, in which are recorded the approximate distances of some of the stars of the first magnitude, will give an idea of the grandeur of space.

TABLE III

RELATIVE DISTANCES OF STARS

Name of Star	Distance in Diameter of the Earth's Orbit	Distance in Quadrillions of Miles	Distance Light-Years
Alpha Centauri	137,500	25	4.35
Sirius	262,500	58	8.36
Procyon	380,500	71	12.00
Aldebaran	473,000	81	13.80
Altair	543,000	101	17.10
Vega	687,500	128	21.70
Capella	937,500	174	29.60
Arcturus	1,097,000	204	34.70

87. There are a few other stars of different magnitudes, the distances of which are about equal to those named in the table, but as to the rest it is only known that they are still more distant. In all probability, the light of the remotest telescopic stars occupies hundreds or thousands of years in coming to the earth. When, at any time, a change in position or appearance of a star is observed, that change did not take place at the time of observation, but occurred ten, a hundred, or a thousand years before that time, according to the star's distance from the earth.

88. Annual Parallax.—The greatest angle subtended at a star by the radius of the earth's orbit is called the star's **annual parallax.** Thus, in Fig. 20, if S represents the sun, S' the star, and E the earth at the time when ES subtends the greatest angle at S', then the angle $ES'S$ is the annual parallax of the star S'.

The parallax of only a few stars has, as yet, been determined, and in no case does it amount to as much as 1 second.

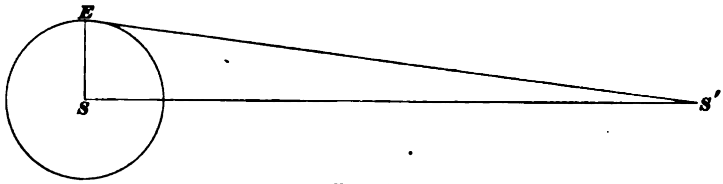


FIG. 20

When the annual parallax of a star is known, its distance can be found by the formula

$$d = r \times \frac{206,265}{S},$$

in which r denotes the radius of the earth's orbit, d the distance of the star, and S its annual parallax in seconds.

The distance found by this formula is then expressed with the radius of the earth's orbit as a unit.

89. The approximate values of the parallaxes of some of the principal stars are given in Table IV.

TABLE IV

APPROXIMATE VALUE OF PARALLAX OF PRINCIPAL STARS

Name of Star	Parallax	Name of Star	Parallax
Alpha Centauri .	.75″	Vega	.150″
Sirius	.33″	Capella	.110″
Procyon	.27″	Arcturus	.094″
Aldebaran . . .	.24″	Pole Star	.089″
Altair	.19″	61 Cygni	.450″

NOTE.—By observations recently made, the values of the parallaxes given in Table IV have been somewhat modified, but they will nevertheless serve to illustrate the magnitude of space.

Expressed in light-years, the distance of a star with a parallax of 1″ is 3.262; hence, in this case, the formula given in the preceding article should be

$$d = \frac{3.262}{S}$$

EXAMPLE.—Find the distance, in light-years, of the pole star.

SOLUTION.—According to Table IV, the parallax of the pole star is .089″. Substituting this value for S in the formula just given,

$$d = \frac{3.262}{.089} = 36.65 \text{ light-yr. Ans.}$$

HOW TO LOCATE THE PRINCIPAL STARS

90. It is very desirable that a navigator should make himself familiar with the position of the stars of the first magnitude, from which, by referring to the star map, the others can be readily found. When, as often happens, the sun has been obscured for a day or two, star observations become of great value; for which reason a navigator should know all the principal stars so as to recognize them during even a very partial clearness of the sky. In order to enable him to do so, a brief explanation will be given of how a few of the brightest and most conspicuous stars can be located.

91. To indicate a particular star, it is customary to mention the constellation in which the star is situated and to add a letter or number by which that star can be distinguished from other stars in the same constellation. Separate names, also, have been given to the most conspicuous.

The letters of the Greek alphabet, which are used for this purpose, are:

α alpha	ι iota	ρ rho
β beta	κ kappa	σ sigma
γ gamma	λ lambda	τ tau
δ delta	μ mu	υ upsilon
ε epsilon	ν nu	φ phi
ζ zeta	ξ xi	χ chi
η eta	o omikron	ψ psi
θ theta	π pi	ω omega

The brightest star in a constellation is denoted by α, the next brightest by β, and so on.

92. There is no difficulty in recognizing the constellation of Ursa Major, or the Great Bear, of which the seven

principal stars are shown in Fig. 21. These seven stars form the Dipper. Referring to the star map, if a line is imagined to be drawn through the stars β and α of the Dipper, and produced about $4\frac{1}{2}$ times the distance from β to α, the end of this line will be near to a bright star. This bright star is Polaris, or the pole star. For this reason, the stars β and α are called the pointers. The pole star is also the star α of the constellation Ursa Minor.

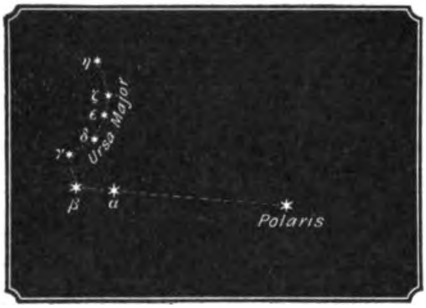


Fig. 21

93. If the handle of the Dipper is produced with a uniform curvature, it will point out the bright star Arcturus in the constellation Bootes. The line joining Polaris to η, the last star in the handle of the Dipper, if produced, passes very near to Arcturus. By means of these two lines, Arcturus can be readily recognized.

94. A line drawn from Polaris perpendicular to the line of the pointers, and on the side opposite the Dipper, passes, at 48° distance, through Capella, another bright star of the first magnitude.

In the opposite direction, and about the same distance from Polaris, is a large white star called Vega; and at one-third the distance from Arcturus to Vega is the bright star Gemma in the constellation Corona. A line drawn from η in the Dipper through Vega and produced to an equal distance beyond it passes through Altair. The line of the pointers carried through Polaris passes through Markab, the principal star in the constellation Pegasus.

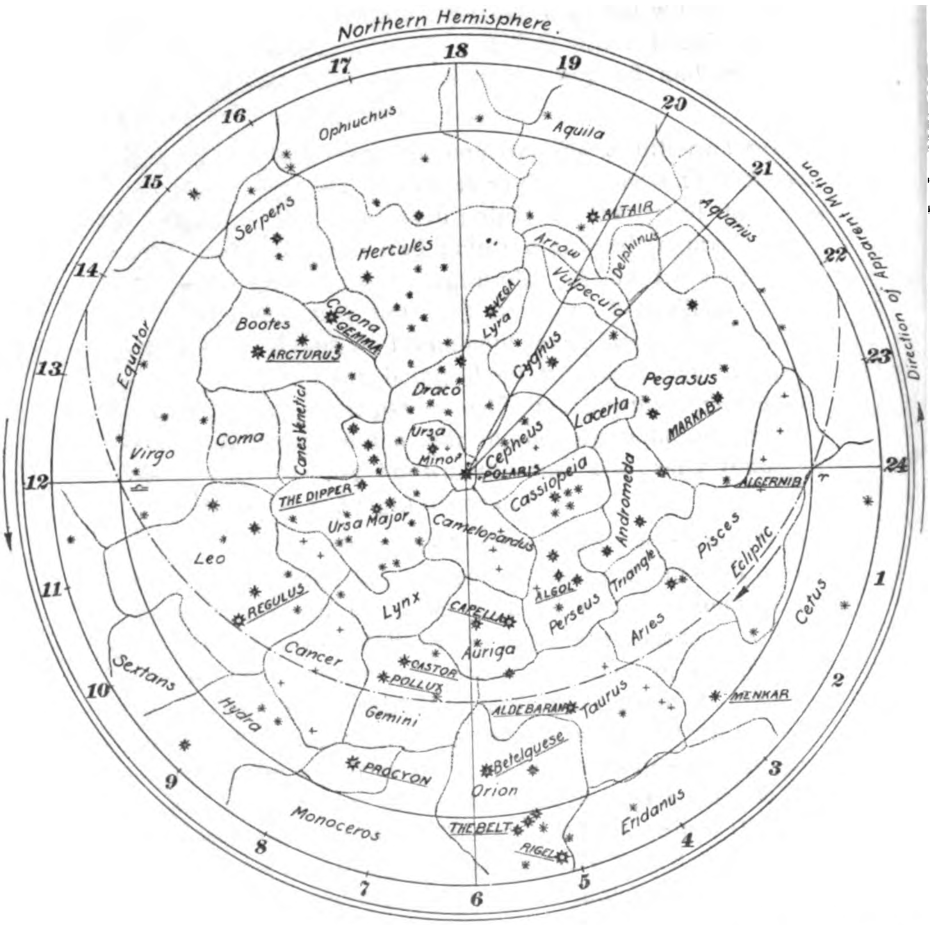
A line from Polaris through Capella passes near Rigel in the constellation Orion; and a line from Rigel in the direction of the Dipper goes through α Orionis and very near Castor in Gemini. A line drawn through η and ζ of the Dipper, in the direction $\eta\,\zeta$, will pass close to Capella and go

through the star Aldebaran in Taurus. A line from Aldebaran through the belt of Orion passes, at about 20° on the other side, through Sirius, the brightest of stars. Sirius and Procyon (to the northward of Sirius), together with α Orionis, form an equilateral triangle. A line from Rigel through Procyon passes, at an equal distance beyond, and very near Regulus in the constellation Leo.

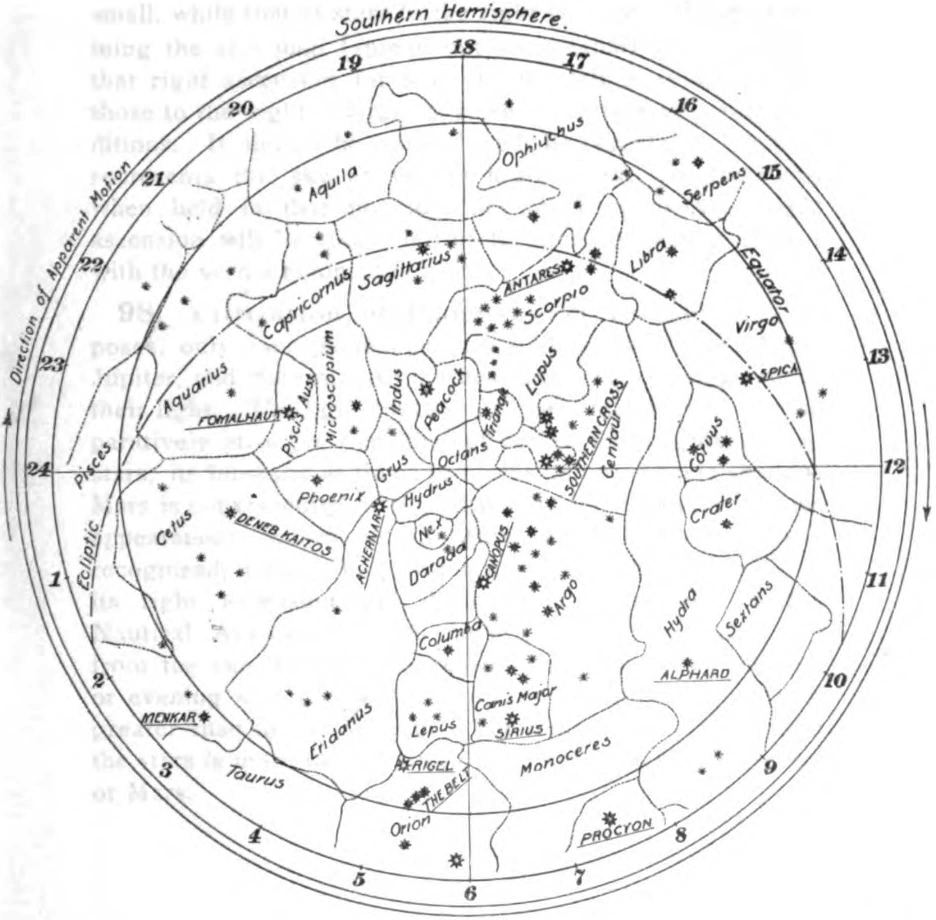
95. In the southern hemisphere, the Southern Cross is about as far from the south pole as the Dipper in the northern hemisphere is from the north pole. To the left of the cross, when on the meridian and pointing toward it, are α and β Centauri, both of the first magnitude. A line from α Orionis through Rigel passes not very far from Fomalhaut, a very bright star. Achernar, Fomalhaut, and Canopus are in line and nearly equidistant, being about 40° apart. A line from Regulus through Spica passes at 45° distance through Antares, a very bright and reddish star in the constellation Scorpio. When a few stars are known, the rest are easily found by their declination and right ascension.

96. On the star map, the hours of right ascension (R. A.) are indicated at the circumferences, being numbered as the figures on a watch face, but with 24 hours instead of 12. By means of these indications the right ascension of any star may be approximately found, and thence, according to methods that will be explained later, the time of its meridian passage. For instance, if the numbers *20* and *21* are connected with the center of the map by means of straight lines, the right ascension of all stars within the space bounded by these lines will lie between 20 and 21 hours. Since the right ascension of a star does not change more than 3 or 4 seconds in a year, it is evident that the values indicated on the map are good for every day of the year.

97. Position of the Vernal Equinox in the Sky. As right ascension is reckoned from the vernal equinox, the approximate position of that point in the sky may be readily fixed any clear night by following an imaginary line from Polaris that passes through or very near the star Alpha in



MAP OF PRINCIPAL STA


Southern Hemisphere.
18
19
17
20
16
21
15
22
14
23
13
24
12
1
11
2
10
3
9
4
8
5
7
6
Direction of Apparent Motion
Ecliptic
Equator
Ophiuchus
Aquila
Serpens
Sagittarius
Capricornus
ANTARES
Libra
Scorpio
Virgo
Aquarius
Microscopium
Indus
Peacock
Lupus
SPICA
FOMALHAUT
Piscis Aust.
Triangle
SOUTHERN CROSS
Centaur
Corvus
Pisces
Grus
Octans
Phoenix
Hydrus
Crater
Cetus
DENEB KAITOS
ACHERNAR
Nex
Dorado
CANOPUS
Argo
Hydra
Sextans
Columba
ALPHARD
MENKAR
Eridanus
Lepus
Canis Major
SIRIUS
Monoceres
RIGEL
Taurus
THE BELT
Orion
PROCYON

Andromeda and Algenib in *Pegasus*. At a distance of 90° from Polaris, along that line, is the vernal equinox. Hence, the right ascension of all stars to the left of that line is small, while that of stars to the right is large. When examining the star map (spread out on a table) the statement that right ascension for stars to the left is small and for those to the right is large may seem contrary to actual conditions. It should be remembered, however, that the map represents the sky above the head of the observer, and when held in that position, the small numbers of right ascension will lie to the left of the line connecting Polaris with the vernal equinoctial point.

98. Utilization of Planets.—For navigational purposes, only four planets are used; they are Venus, Mars, Jupiter, and Saturn. All of these are easily recognized by their light. The light emitted by Venus and Jupiter is comparatively stronger than that of Sirius, the brightest of all stars; its intensity at times produces an appreciable shadow. Mars is conveniently distinguished by its decidedly reddish appearance. Saturn, on the other hand, is not so easily recognized; usually, its position must be found by the aid of its right ascension and declination, as recorded in the Nautical Almanac. Venus never recedes more than 48° from the sun, and for this reason it is named the morning or evening star, according as its right ascension is less or greater than that of the sun. The motion of Venus among the stars is more rapid than is the motion of either Jupiter or Mars.

THE SEXTANT

ITS CONSTRUCTION AND USE

99. Law of Reflected Rays.—The **sextant** is an instrument for measuring angular distances, especially at sea, where the motion of the ship renders the use of fixed instruments impossible. The construction of this instrument is based primarily on the laws of reflection of light from plane mirrors. These laws are as follows:

I. *The angle of reflection is equal to the angle of incidence.*

II. *The incident and the reflected ray are both in the same plane, which is perpendicular to the reflecting surface.*

III. *If a ray of light is reflected twice in the same plane by two plane mirrors, then the angle formed by the first and last direction of the ray is double the angle of the mirrors.*

Referring to Fig. 22, in which AB represents the reflecting surface and DC a line perpendicular to the plane of this surface, assume that a ray of light from m falls on AB at C; it will then be reflected (thrown back) in the direction of Cn, so that the *angle of incidence* mCD is equal to the *angle of reflection* nCD. This is the first law.

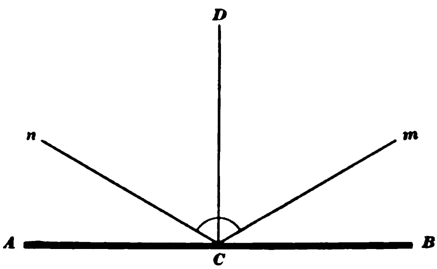


Fig. 22

The second law says that both of these angles are in the same plane, and that this plane is perpendicular to the plane of AB. The third law is explained in connection with the construction of the sextant.

100. Description of Sextant.—The sextant, which is shown in Fig. 23, derives its name from the extent of its graduated arc, which is a sixth part of a circle. This instrument consists of a metal frame CDE, the arc DE of which is graduated from 0° to 120° or 150°, each degree being subdivided into 10′, 15′, or 20′, according to the size and perfection of the instrument; this arc DE is usually known as the *limb*. C and B are two glass reflectors, the planes of which are perpendicular to the plane of the frame; B, called the *horizon glass*, is rigidly fixed to the frame of the instrument,

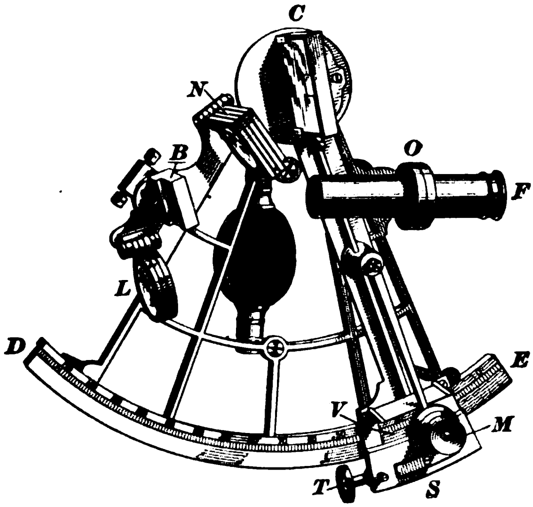


FIG. 23

while C, called the *index glass*, is attached to the *index bar* CS at the center of the instrument, and follows the movement of that bar. The horizon glass, half of which is silvered while the other half is transparent, is adjusted so that its plane is parallel to that of the index glass when zero on the index bar coincides with the zero mark on the limb. F is a telescope, which is screwed into the collar O. On the index bar, immediately below the graduations on the limb, is affixed a vernier plate V. The index bar is fastened to the limb by means of a clamp screw (not shown in the

figure) on the under side of the arc DE. T is the tangent screw by means of which a slight motion is given the index bar after it has been fastened by the clamp screw; M is a magnifying glass for reading the graduation on the limb and vernier; N and L are colored shades that are used to prevent the glare of the observed body from affecting the eye of the person making observations.

101. Theory of Construction.—The theory of the construction of a sextant may be explained by means of Fig. 24.

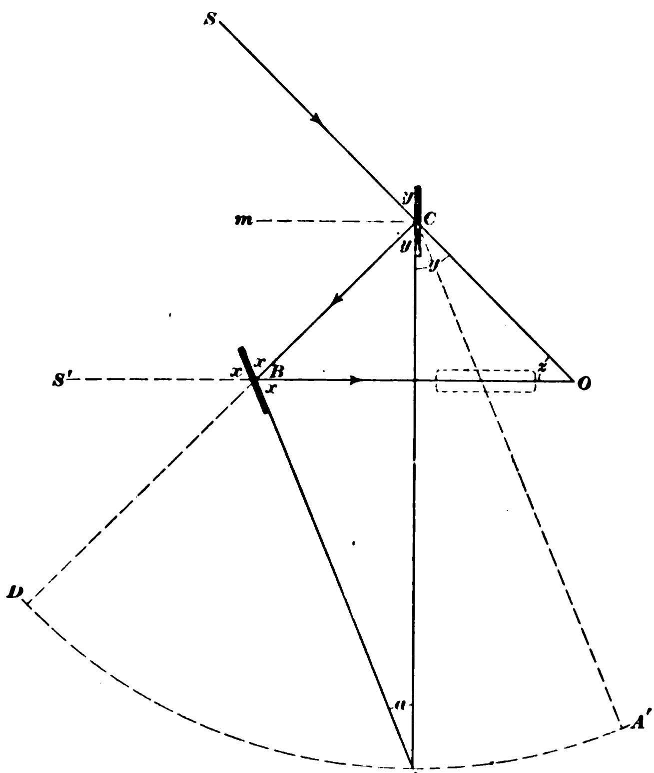


FIG. 24

Assume that it is required to measure the angular distance between S and S'. The instrument is then held in such

a position that its plane passes through both the objects, while the index bar is set at the zero mark A', placing the two mirrors C and B parallel with each other. The index bar being pushed forwards to A, so that the reflected image of S coincides with the direct image of S' seen through the transparent half of the horizon glass, the angle $C O B$ measures the angular distance required, and $B A C\ (= A C A')$ measures the angle between the planes of the two mirrors B and C.

Now, since the angle of incidence $S C m$ and the angle of reflection $m C B$ are equal, it follows that the angles y and $B C A$, which are the complements of the former, are also equal. Furthermore, since the angle $A C O$ is equal to the opposite vertical angle y, it is evident that the three angles y, $B C A$, and $A C O$ are all equal and can be denoted by the same letter y.

Similarly, the angles x, x, and x are all equal. Then, according to geometry, in the triangle $B C A$,

$$x = a + y$$

Multiplying by 2,

$$2x = 2a + 2y$$

Similarly, in the triangle $B C O$,

$$2x = 2y + z$$

Substituting in this equation the value of $2x$ in the former,

$$2a + 2y = 2y + z$$

Whence, $C O B$, or $z = 2a$, or the angle at the eye of the observer is twice the angle between the planes of the mirrors C and B. However, the angle a is equal to $A C A'$, since $A B$ and $A' C$ are parallel; and this angle is measured by the arc $A A'$ of the limb. Hence, the observed angle z is twice the angle $A C A'$, which is measured by the arc $A A'$. For this reason, the arc $A' A$, and consequently the whole limb $A' D$, is graduated in such manner that *each half degree is marked as a whole degree*, and the observer is thus enabled to read the measured angular distance between the two objects S and S' directly from the limb.

102. Graduations of the Sextant.—As previously stated, the limb of a sextant is graduated into degrees,

which are subdivided into 20′, 15′, or 10′. These graduations commence from right to left when the instrument is held before the observer. At the end of the index bar *C*, Fig. 25, just below the graduations on the limb *m n*, is affixed the vernier plate *a b*, at the right-hand side of which is a spear-shaped mark called the *index*. If this index points directly

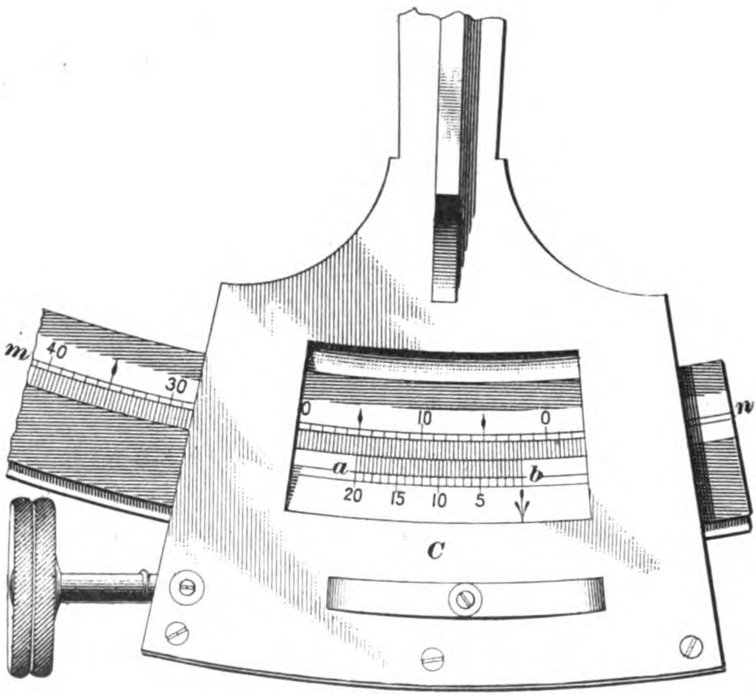


Fig. 25

to a division on the limb, for instance, as in the figure, to that of the second degree, the reading will be at once obtained as 2°. But if, as is more likely, the index points between the two divisions, as in Fig. 26, between 1° 20′ and 1° 40′, the reading will be *about* 1° 30′.

103. Rule for Reading a Sextant.—In order to obtain greater accuracy, the graduations on the limb and on the vernier are used as follows:

Rule.—*First read on the limb the degrees and divisions nearest the index mark; then glance along the graduations on the vernier until one of its divisions is found that coincides exactly with one of the divisions on the limb; read the number of minutes and fraction of minutes thus indicated on the vernier and add this to the number of degrees and minutes previously read on the limb. The result is the exact angle measured.*

Thus, in Fig. 26, the division on the limb nearest the index mark indicates 1° 20′. Then, glancing along the graduations on the vernier, the mark indicating 11′ is found to coincide with one of the divisions of the limb. Adding this number of minutes to the one previously obtained, the exact angle measured will be 1° 20′ + 11′ = 1° 31′.

104. The Vernier and Fineness of Reading.—The **vernier**, which received its name from the inventor, Pierre Vernier, a French mathematician, is graduated in such a manner that it contains one part more than an equal portion of the limb. For instance, in Fig. 26 it will be seen that 40 divisions of the vernier cover a space equal to 39 divisions of the limb. In general, to find the fineness of the reading of a sextant, proceed as follows:

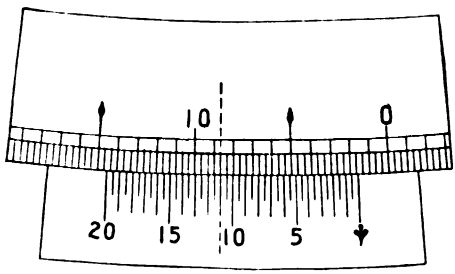


FIG. 26

Divide the number of minutes (reduced to seconds) in 1 division on the limb by the number of parts into which the vernier is divided.

Thus, in Fig. 26, 1 division on the limb represents 20′, and the vernier is divided into 40 parts. The fineness of reading is, therefore,

$$\frac{20'}{40} = \frac{1{,}200''}{40} = 30''$$

Again, if 1 division of the limb equals 10′ and the vernier is divided into 60 equal parts, the fineness of reading will be

$$\frac{10'}{60} = \frac{600''}{60} = 10''$$

In good sextants, each degree on the limb is usually divided into 6 parts, each part representing 10′; and the vernier is constructed in such a manner that, if completely divided, 120 of its divisions will cover a space of 119 divisons on the limb. The fineness of reading for such an instrument would consequently be equal to $\frac{10'}{120} = \frac{600''}{120} = 5''$; but, since 10″ is sufficiently close for nautical purposes, instrument makers as a rule omit every alternate division on the vernier and thus reduce the fineness of reading to 10″.

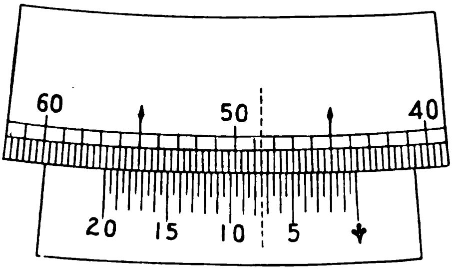


Fig. 27

105. Illustrative Examples.—When the first attempt is made to read a sextant, several divisions on the limb and the vernier may seem to coincide; this, however, is only an illusion of the unexperienced eye. After some practice it will be a comparatively easy matter to single out the division on the vernier that coincides exactly with the one on the limb.

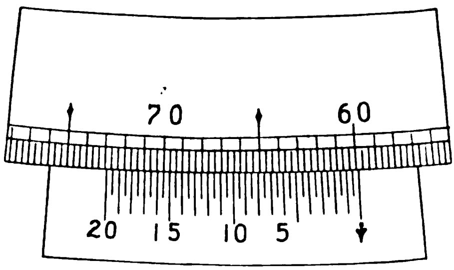


Fig. 28

Example 1.—How many degrees, minutes, and seconds are contained in the angular distance represented in Fig. 27?

SOLUTION.—According to the rule of Art. **103**, there are

on the limb	43° 40′
on the vernier	$7\frac{1}{2}'$
sum =	43° $47\frac{1}{2}'$

Hence, the angular distance measured is 43° 47′ 30″. Ans.

EXAMPLE 2.—The altitude of a celestial body has been measured. The position of the vernier is shown in Fig. 28; what is the altitude?

SOLUTION.—According to the rule of Art. **103**, there are

on the limb	59° 40′
on the vernier	$15\frac{1}{2}'$

Hence, the observed altitude = 59° 55′ 30″. Ans.

106. Readings Off the Arc.—When readings are made "off the arc," that is, when the index mark of the vernier stands to the right of the zero mark on the limb, the following rule should be adhered to:

Rule.—*Read on the limb the number of degrees and minutes from the zero mark to the division nearest the index mark (left side), and add to this the number of minutes and fraction of minutes, read toward the right, from the last mark on the vernier to the coincident division.*

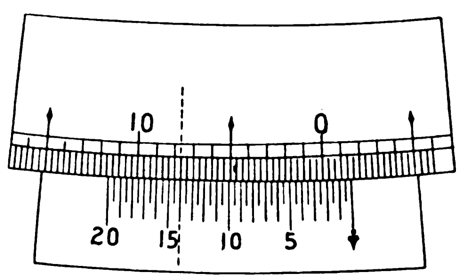


FIG. 29

Thus, on the limb, in Fig. 29, there are 1° 20′, and from the last, or *20′*, mark on the vernier to the coincident division, there are 6′. Hence, the measured angle = 1° 20′ + 6′ = 1° 26′.

107. To Adjust the Sextant.—At intervals, the sextant should be examined, and, if necessary, subjected to certain adjustments. The principal adjustments are the following:

1. *The index glass should be perpendicular to the plane of the instrument.*

2. *The horizon glass should be perpendicular to the plane of the instrument.*

3. *The line of collimation, or center line of the telescope, should be parallel to the plane of the instrument.*

4. *The horizon glass should be parallel to the index glass when the index mark is at zero.*

108. To Adjust the Index Glass.—Place the index bar near the middle of the limb. Then look into the index glass and observe whether the limb seen direct and its reflected image form a continuous line; if they do, the glass is perpendicular to the plane of the instrument. However, if the reflected limb appears to be above or below that part of the limb seen direct, the glass needs an adjustment. In the former case, the glass leans forwards; in the latter case, it leans backwards. The adjustment is made by means of the screws at the back of the glass.

109. To Adjust the Horizon Glass.—Look through the telescope and direct it toward a star or other well-defined object; move the index bar so that the reflected image passes over the image seen direct. If these images coincide exactly, the glass is perpendicular; if not, it needs an adjustment. This is made by means of a screw, which, in some instruments, is placed under the glass; in others, behind; and in still others, at the side.

110. To Adjust the Telescope.—Place the telescope in the collar of the sextant and turn the eyepiece around until the two wires are parallel to the plane of the instrument. Then select two celestial bodies as the sun and the moon, not less than 90° apart, and bring the reflected image of the sun in contact with the direct image of the moon at the wire that is nearer the plane of the sextant. This having been done, move the instrument slightly so as to bring the two bodies to the other wire. If the contact still remains perfect, the center line of the telescope is parallel to the plane; but if the edges of the two objects overlap, the farther end of the telescope is inclined away from the plane; if the edges have separated, the same end is inclined toward the plane of the instrument. The adjustment is made by loosening and tightening the two screws in the collar according to requirements.

This adjustment is seldom required at sea, as the error that results from the center line not being parallel to the plane does not sensibly affect the ordinary observations. On some instruments there are no screws for this adjustment, the parallelism of the telescope then being supposed to have been carefully made before the instrument left the maker's hands.

111. Index Error.—The error resulting from the index glass not being parallel to the horizon glass when the index mark is at zero, is called the **index error.** This error is frequently found on sextants, but as a rule is not removed unless it exceeds 3′ or 4′; if less than this, its amount is applied to the observed angle, according to its sign.

In connection with finding the index error, it is convenient to denote the graduated portion of the limb that lies to the right of the zero mark as negative (−), and that portion to the left as positive (+). In other words, readings *on* the arc are positive and those *off* the arc are negative. The index error is usually determined either by the sun or by the sea horizon.

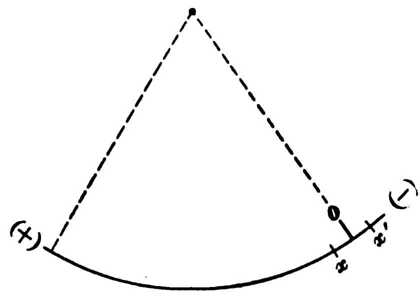


FIG. 30

112. To Find the Index Error by Means of the Sun.—To determine the index error by measuring the apparent diameter of the sun, proceed as follows: First bring the lower edge of the reflected image so that it touches the upper edge of the image seen direct; this will bring the index mark on the negative portion of the limb, or at x', Fig. 30. Read off the angle thus found, and mark it with a negative sign. Direct the instrument again toward the sun, and bring the upper edge of the reflected image in contact with the lower edge of the image seen direct. This brings the index mark on the positive side of the limb at x; hence, the angle then read off is marked with the positive sign. Take the

algebraic sum of the two readings, divide by 2, and give it a sign opposite that of the greater reading. The result is the index error of the instrument.

If the observations are correct, one-half the numerical sum of the readings will equal the sun's diameter, as found in the Nautical Almanac, for the day the observations were taken. This will therefore serve as a check, provided the sun's altitude is greater than 20° when the observation is made.

In order to illustrate the foregoing, let it be assumed that on March 30, 1896, the sun's diameter was measured both ways, the respective readings being as follows:

$$\begin{aligned} \text{Reading on negative side} &= -\ 33'\ 20'' \\ \text{Reading on positive side} &= \underline{+\ 30'\ 50''} \\ \text{Algebraic sum} &= -\ \ \ 2'\ 30'' \end{aligned}$$

Denoting half of this algebraic sum by a sign opposite that of the greater reading, the index error in this case will be + 1′ 15″. In order to verify the correctness of the index error found, compare the half sum of numerical readings with the sun's diameter for the given day. The sum of the numerical readings is 64′ 10″; hence, the half sum is 32′ 5″.

According to the Nautical Almanac of 1896, the sun's semi-diameter on March 30 was 16′ 2″; hence, its apparent diameter on that day was 32′ 4″. Since this agrees very nearly with the half sum of the numerical readings, the value of the index error as just obtained may be considered as correct.

113. Serial Readings.—When determining the index error by the sun, it is advisable to take several readings in succession on and off the arc. The mean of these readings will give a closer value of the error than that found by a single observation. Sometimes, the sextant may be affected by the heat of the sun to such an extent that the value of the index error may differ considerably before and after observations are made. A case in point is shown by the following:

First Readings

	On Arc	Off Arc
	+ 32′ 20″	− 30′ 50″
	+ 32′ 30″	− 30′ 60″
	+ 32′ 30″	− 30′ 50″
	+ 32′ 20″	− 30′ 60″
Sum =	+ 128′ 100″	− 120′ 220″
Mean =	+ 32′ 25″	− 30′ 55″

Positive reading = + 32′ 25″
Negative reading = − 30′ 55″
Algebraic sum = + 1′ 30″
Index error = − 45″

Second Readings

	On Arc	Off Arc
	+ 32′ 10″	− 31′ 20″
	+ 32′ 0″	− 31′ 10″
	+ 32′ 0″	− 31′ 10″
	+ 32′ 10″	− 31′ 10″
Sum =	+ 128′ 20″	− 124′ 50″
Mean =	+ 32′ 5″	− 31′ 12″

Positive reading = + 32′ 5″
Negative reading = − 31′ 12″
Algebraic sum = + 0′ 53″
Index error = − 26″

In practice at sea and under ordinary conditions of temperature, however, the effect due to the expansion of the metal in the sextant is disregarded.

114. To Find the Index Error by Means of the Sea Horizon or by a Star.—To determine the index error by means of the sea horizon or by a star, proceed as follows: Select a day when the sea horizon is well defined. Place the index mark of the sextant exactly at zero, and direct the instrument, holding it in a perpendicular position, toward the horizon. Then, if that part of the horizon seen direct through the transparent portion of the horizon glass does not coincide with the reflected part, move the index bar until it does, and tighten the clamp screw. The angle then read off is the index error and is *additive* if the index mark falls to the *right* of the zero mark, but *subtractive*, if to the *left* of the zero mark. When using a star, proceed in exactly the same manner.

115. Removal of Index Error.—The index error may be removed by turning the horizon glass, by means of its adjusting screws, around an axis perpendicular to the plane of the instrument. It is advisable, however, to have this adjustment made by an instrument maker or some other competent person.

Note.—When the instrument is once in order, it should not be tampered with too often. If continually subjected to "adjustment" by unskilful hands, the chances are that in a comparatively short time the instrument will become worthless.

116. How to Use the Sextant.—When about to measure angles and altitudes with a sextant, for instance the altitude of the sun, a beginner should proceed as follows: Hold the instrument by the handle in the right hand and place the index bar very near but *not* on zero; turn up one or more of the colored shades in front of both the index and the horizon glass, according to the brightness of the sun, using a different color for each in order to better distinguish between the real and the reflected image. Direct the instrument toward the sun with the eye close to the eyepiece of the telescope, as shown in Fig. 31. Two images of the sun will now be seen—one real and one reflected. To ascertain which one is the reflected image, move the index bar slightly; the moving image is of course the reflected one. Then, in order to measure the altitude, bring the reflected image of the sun down to the horizon by gently pushing the index bar forwards, being careful to follow a line perpendicular to the horizon. This having been done, tighten the clamp

FIG. 31

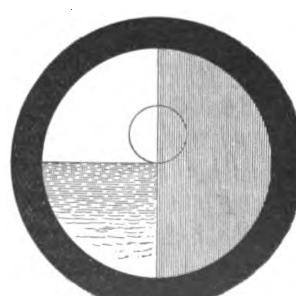


FIG. 32

screw and use the tangent screw to get a more perfect observation. When the image touches the horizon exactly, it will appear in the horizon glass, looking through the telescope, as shown in Fig. 32.

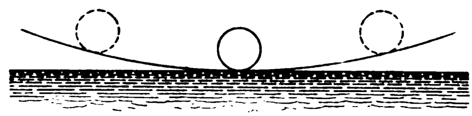


FIG. 33

To make sure that the point of contact is vertically below the sun, oscillate the instrument from right to left, and vice versa. This movement will cause the image to skim the horizon in the manner shown in Fig. 33 and will enable the observer to

FIG. 34

measure the exact required vertical altitude. After the altitude has been measured, hold the instrument as shown in Fig. 34, and read off the measured angle according to rule, being very careful not to touch either the clamp or tangent

screw before the angle is read off and noted on a piece of paper.

117. When measuring the angular distance between two celestial bodies or between two terrestrial objects, the instrument should be held so that its plane passes through the two objects. The reflected image of one object is then brought in contact with the other object seen direct through the transparent portion of the horizon glass, and the angle is read off.

118. The Quadrant.—The **quadrant** is an instrument closely resembling the sextant and is used by navigators for measuring angles and altitudes. This instrument is constructed on the same principle as the sextant, and has similar parts; its limb, however, is only an eighth part of a circle, or 45°. Like the sextant, being an instrument of double reflection, every half-degree is marked as one; consequently, the quadrant can be used for measuring angles up to 90° only. The adjustments of the quadrant are similar to those of the sextant.

119. Circle of Reflection.—The **circle of reflection** is an instrument that, in the opinion of many observers, is decidedly superior to the sextant and quadrant in measuring large angles. In this instrument, the errors arising from a faulty division of the limb and want of parallelism in the surfaces of mirrors and colored shades are reduced to a minimum; also, the error that might arise in a sextant, because the mirrors are not parallel when the index is on the zero mark, is entirely eliminated. The use of the circle of reflection among navigators, however, is very limited at present. With the introduction of chronometers and the consequent decrease of measuring large angles in lunar observations, and also on account of great improvements in the construction of sextants, the circle of reflection, as a navigator's instrument, has become quite rare.

CORRECTION OF ALTITUDES

120. The altitude of a celestial body, as measured by a sextant, is called the *observed altitude;* and in order to obtain the *true altitude* some or all of the following corrections must be applied: (1) Index error of the sextant, if any, (2) dip of the horizon, (3) refraction, (4) parallax, and (5) semi-diameter.

The necessity for applying these corrections arises from the fact that all observations made at different points on the earth's surface must be reduced to the *center of the earth*, as if they were taken at the center of the rational horizon. The nature of each correction will now be described in the order in which it is given, except that of the index error, which has already been explained.

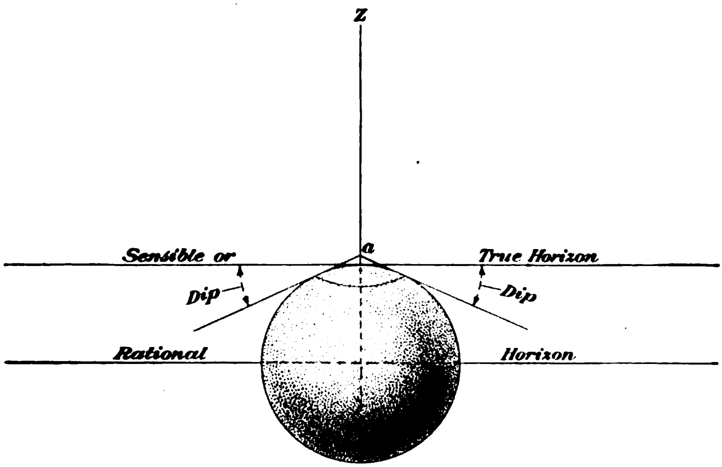


Fig. 35

121. Sensible, or True, Horizon.—In connection with and before considering the subject of dip, it should be stated that aside from the rational horizon there are two other horizons that must be taken into consideration; namely, the *sensible* and the *sea horizon*.

The **sensible, or true, horizon** is the plane passing through the point where the observer stands; it is perpendic-

ular to the direction of the observer's zenith, and is consequently parallel with the rational horizon, as shown in Fig. 35. The sea horizon, as previously explained, is the apparent boundary between the sky and the sea.

122. Dip of the Horizon.—Let OA, Fig. 36, represent the height of the eye of the observer; S a celestial body, the altitude of which is to be measured; and OH a horizontal line that may be considered as the sensible horizon, owing to the great distance of S. Then, the angle SOH is the required altitude. From O draw a tangent to the earth's surface. The point T will then be the most distant point of the surface visible from O; or, in other words, the sea horizon with which the observed body has been brought into contact. Hence, the altitude measured by the sextant is the angle SOH' instead of SOH; the difference between these two angles, or the angle d, is called the **dip**, or the **dip of the horizon.**

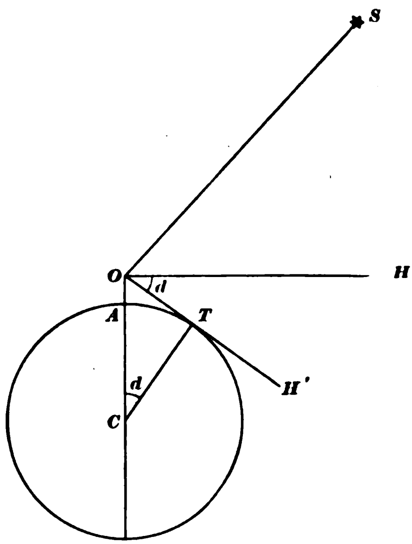


FIG. 36

From the figure, it is evident that in order to obtain the required apparent altitude SOH the amount of dip must be subtracted from the measured altitude. Hence, the dip is always *subtractive* from the observed altitude.

123. To Find the Amount of Dip.—Connect the point T, Fig. 36, with the center of the earth C; then, the dip HOH' will be equal to the angle OCT at the center of the earth since COT is complement to both.

Let h represent the height of the eye OA, r the radius of the earth $AC (= CT)$, and d the dip.

Then, in the triangle OCT,

$$\tan d = \frac{OT}{TC} \qquad (1)$$

Referring to the same triangle,

$$\overline{OT}^2 = \overline{OC}^2 - \overline{TC}^2,$$

or

$$\overline{OT}^2 = (r+h)^2 - r^2,$$

or

$$\overline{OT}^2 = 2rh + h^2$$

Now, since h^2 is insignificant in comparison with $2rh$, it may, without appreciable error, be rejected.

Hence, $OT = \sqrt{2rh}$

Substituting this value of OT in formula **1**,

$$\tan d = \frac{\sqrt{2rh}}{TC} = \sqrt{\frac{2rh}{r^2}} \qquad (2)$$

Whence, $\tan d = \sqrt{\frac{2h}{r}}$, very nearly

With this formula, the effect of terrestrial refraction taken into consideration, is calculated the value of the dip for every probable height of the observer. A table giving the value of the dip of the horizon under normal atmospheric conditions is found on page 165 of the Nautical Tables. These values may be slightly affected by abnormal conditions of the atmosphere, but are, as a rule, sufficiently accurate for practical purposes. An instrument called the *navigator's prism* has recently been introduced for determining the true value of the dip; it was invented by Commander J. B. Blish, of the United States Navy, and may be attached to any sextant. Directions for use accompany each prism.

124. Since the value of dip depends on the height of the observer's eye above the surface of the sea, it is advisable always to ascertain beforehand the exact vertical distance from the water-line to the bridge, or to the place usually occupied by the observer when measuring altitudes. Due allowance should be made for any reduction or increase in this vertical distance when the ship is loaded or light, or when it has a considerable list to either side.

125. Refraction.—A ray of light travels in a straight line as long as its path is in a medium of uniform density; but when the ray passes obliquely from one medium into another of different density, or from one stratum of a medium into another of different density, it undergoes a change of direction at the surface of the denser stratum. This bending of the ray is called **refraction.** The air that surrounds the earth gradually increases in density as the surface of the earth is approached. At the height of 4 miles, the density of the air is only one-half as great as at the surface. Hence, when a ray of light from the sun S, Fig. 37, enters the earth's atmosphere obliquely, it is always bent *downwards;* that is, instead of traveling in a straight path from S to an observer at o, it goes from S to a, then to b, c, d, etc., successively, until it reaches the observer's eye. Now, the apparent position of a body depends on the direction in which the light enters the observer's eye; hence, the sun appears to be at S' instead of in its true position S. Refraction, therefore, tends to increase the altitude of the sun and consequently the correction for refraction is *subtractive* from the observed altitude.

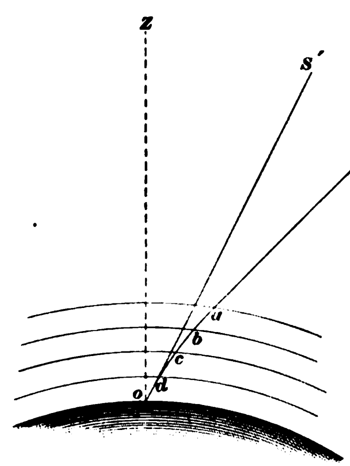


FIG. 37

If, however, the observed body is exactly in the zenith Z, a ray of light from it to the observer enters the atmosphere perpendicularly and not obliquely. Under these circumstances, the ray does not suffer refraction, and, consequently, the position of a body in the zenith is not affected by refraction.

126. For different conditions of the atmosphere, the refraction for the same altitude is, of course, different. The

table on page 164, Nautical Tables, however, gives the value of the correction for the *mean* atmospheric condition (50° F). Sometimes, a second table is annexed containing a factor to modify the corrections of the former table according to the actual condition of the atmosphere, as indicated by the thermometer and barometer at the time and place of observation, but this additional table is but seldom used at sea. It should be remembered that refraction does not alter the *bearing* of a celestial body, but affects only its altitude by causing it to appear higher above the horizon than it actually is.

127. Parallax.—The angle formed by a line joining a celestial body with the point of observation and a second line joining the same body with a certain point of reference, such as the center of the earth, is called the **parallax** of the celestial body. Thus, if P', Fig. 38, is the celestial body, A the point of observation, and C the point of reference, then the angle $A P' C$ is the parallax of the body P'. When the center of the earth is taken as the point of reference, the parallax of a body is called its **geocentric parallax.** Since the position of the moon or of a planet is always referred to the earth's center, the geocentric parallax of one of these bodies is called simply its *parallax.* The moon has the greatest parallax of all celestial bodies on account of its proximity to the earth.

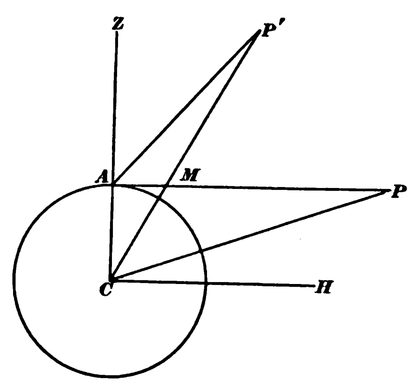


FIG. 38

128. The geocentric parallax of a body depends on its distance from the zenith. Let A, Fig. 38, be the position of the observer, C the center of the earth, and Z the zenith. The lines ZA and ZC coincide; hence, the parallax of a body in the zenith is zero. The greater the zenith distance of a

body, the larger is its parallax; and the parallax is greatest when the body is on the horizon, as at P.

If CH of the rational horizon is drawn in the plane ZCP', then $P'AP$ is the apparent altitude of the body P', and $P'CH$ is its geocentric altitude.

Now, $P'CH = P'MP$

But, $P'MP = P'AP + AP'C$

Hence, $P'CH = P'AP + AP'C$

That is, the geocentric altitude is found by *adding* the parallax to the apparent altitude (corrected for refraction).

Owing to this relation between parallax and altitude, geocentric parallax is frequently called *parallax in altitude;* it is also known as *diurnal parallax*, because it passes through a complete cycle of values every day, being greatest when the body is on the horizon and least when the body is on the meridian.

129. The **horizontal parallax** of a body is its geocentric parallax when it is on the horizon. Thus, in Fig. 38, the angle APC is the horizontal parallax of the body P. Evidently, then, the horizontal parallax of a body may be defined as *the angular semi-diameter of the earth as seen from that body*. For instance, when the moon's horizontal parallax is said to be 60′, it means that, seen from the moon, the earth's diameter appears to be 2 × 60′ or 120′.

As stated in a previous article, stars have, with a few exceptions, no sensible parallax. On page 165 of the Nautical Tables is given the sun's parallax in altitude for different values of the altitude. The Nautical Almanac contains the moon's horizontal parallax for each noon and midnight; it also contains the horizontal parallaxes of the principal planets used for observations at sea.

130. Parallax of the Moon.—When the horizontal parallax ($H.\ P.$) of a celestial body is known, its parallax in altitude ($P.\ A.$) is conveniently found by the formula

$$P.\ A. = H.\ P. \times \cos A.\ A.,$$

where $A.\ A.$ represents the apparent altitude of the center, corrected for refraction. In reference to the moon, the

combined value of its parallax in altitude and refraction may be found directly from the tables on pages 168 to 176, inclusive, of the Nautical Tables, in the following manner: Assume the apparent altitude of the moon's center to be 33° 43′ 35″, and the horizontal parallax, 61′ 19″; then, by inspection of the tables:

Correction for apparent altitude 33° 40′ and horizontal parallax 61′	= 49′ 20″	N. T., page 170
Correction for remaining seconds of parallax (19″)	= + 16″	
Correction for remaining minutes of altitude (4′)	= − 2″	
Algebraic sum = total correction	= 49′ 34″	

It should be noted that the apparent altitude used for finding this correction is the apparent altitude of the moon's *center*.

131. Semi-Diameter.—When observing a celestial body having a sensible disk, it is necessary to find the altitude of its center. Hence, if the *lower* edge, or limb, of a celestial body has been brought into contact with the horizon, the angular semi-diameter of the observed body must be *added* to its apparent altitude in order to get the apparent altitude of the center; if the *upper* edge of the observed body has been brought in contact, the angular semi-diameter must be *subtracted* to obtain the same result. Since telescopes of only weak magnifying power are used in sextants, the small semi-diameters of the planets may be disregarded, and only those of the sun and moon taken into consideration.

132. Where Semi-Diameters Are Recorded.—The semi-diameter of the sun is taken directly from the Nautical Almanac, where it is given for every day of the year. The moon's semi-diameter is also tabulated in the Nautical Almanac; that is, its horizontal semi-diameter, or the semi-diameter corresponding to the time when the moon is on the horizon. The semi-diameter of the moon, however, varies with the altitude, being least when the moon is on the

horizon and greatest when it is in the zenith; this variation is known as the *augmentation of the moon's semi-diameter.* A table containing the value of this augmentation for different altitudes of the moon is found on page 167 of the Nautical Tables. The augmentation is always *additive* to the horizontal semi-diameter.

133. Examples Showing Corrections Applied. Having explained the nature of all corrections that are to be applied to an observed altitude in order to find its true altitude, a few examples illustrating the application of the several corrections will now be given. First, however, the following should be committed to memory:

The *observed altitude* is that read on the sextant. When this has been corrected for index error, dip, and semi-diameter, the result is called the *apparent altitude* of the center, and the application to this of the corrections for refraction and parallax produces the *true altitude.*

134. Symbols and Abbreviations.—In the examples that follow, the sun, moon, and stars are indicated by the symbols ☉, ☽, ✳, respectively. A horizontal dash over or under the symbols representing the sun or the moon shows whether the upper or lower limb is observed. Thus,

$\underline{\odot}$ = sun's lower limb;
$\overline{☽}$ = moon's upper limb;
$\ominus$ = sun's center.

Besides these symbols, the following abbreviations are used:

Obs. Alt. = Observed Altitude;
App. Alt. = Apparent Altitude;
True Alt. = True Altitude;
Par. = Parallax in Altitude;
I. E. = Index Error;
S. D. = Semi-Diameter;
Ref. = Refraction.

The letters N. T. refer to the collection of Nautical Tables accompanying this Course. The letters N. A. denote the Nautical Almanac.

Example 1.—The observed altitude of the sun's lower limb was 47° 32′ 15″; the index error = + 2′ 10″; the height of the eye = 15 feet; the semi-diameter, according to Nautical Almanac = 15′ 49″. Find the true altitude.

Solution.—

Obs. Alt. $\underline{\odot}$	=	47° 32′ 15″	
I. E.	= +	2′ 10″	
		47° 34′ 25″	
Dip	= −	3′ 48″	(N. T., page 165)
App. Alt. $\underline{\odot}$	=	47° 30′ 37″	
⊙ S. D.	= +	15′ 49″	(N. A.)
App. Alt. $\ominus$	=	47° 46′ 26″	
Ref.	= −	52″	(N. T., page 164)
		47° 45′ 34″	
⊙ Par.	= +	6″	(N. T., page 165)
True Alt.	=	47° 45′ 40″.	Ans.

Note.—The correction for refraction should be taken out, not for the apparent altitude of the center, but for the apparent altitude of the lower or the upper limb. For observations of the moon, use the apparent altitude of the moon's center.

Example 2.—On May 10, 1899, the observed altitude of the sun's lower limb was 67° 14′ 20″; the index error = + 1′ 20″; the height of the eye = 20 feet; the semi-diameter on the date mentioned = 15′ 52″. Required, the true altitude.

Solution.—

Obs. Alt. $\underline{\odot}$	=	67° 14′ 20″	
I. E.	= +	1′ 20″	
		67° 15′ 40″	
Dip	= −	4′ 23″	(N. T., page 165)
App. Alt. $\underline{\odot}$	=	67° 11′ 17″	
⊙ S. D.	= +	15′ 52″	(N. A.)
App. Alt. $\ominus$	=	67° 27′ 9″	
Ref.	= −	24″	(N. T., page 164)
		67° 26′ 45″	
⊙ Par.	= +	3″	(N. T., page 165)
True Alt.	=	67° 26′ 48″.	Ans.

Note.—It will be noticed in this example that the parallax does not amount to much. In altitudes of 70° or more the parallax may be disregarded.

Example 3.—On January 12, 1899, the observed altitude of the sun's upper limb was 37° 24′ 30″; the index error = − 1′ 42″; the height of the eye = 19 feet; the semi-diameter = 16′ 18″. Required, the true altitude.

SOLUTION.—

$$\begin{array}{rl}
\text{Obs. Alt. } \bar{\odot} & = 37^\circ\ 24'\ 30'' \\
\text{I. E.} & = -\quad 1'\ 42'' \\ \hline
 & \ 37^\circ\ 22'\ 48'' \\
\text{Dip} & = -\quad 4'\ 16'' \\ \hline
\text{App. Alt. } \bar{\odot} & = 37^\circ\ 18'\ 32'' \\
\odot\text{ S. D.} & = -\quad 16'\ 18'' \\ \hline
\text{App. Alt. } \ominus & = 37^\circ\ 2'\ 14'' \\
\text{Ref.} & = -\quad 1'\ 15'' \\ \hline
 & \ 37^\circ\ 0'\ 59'' \\
\odot\text{ Par.} & = +\quad 7'' \\ \hline
\text{True Alt.} & = 37^\circ\ 1'\ 6''. \text{ Ans.}
\end{array}$$

In this example, the sun's upper edge being brought in contact with the sea horizon, the semi-diameter is subtracted from the apparent altitude. In practice at sea, the upper edge is seldom used for contact, the use of the lower edge, or limb, being more convenient and the result more trustworthy.

EXAMPLE 4.—On May 3, 1899, the observed altitude of Jupiter's center was $16^\circ\ 38'\ 30''$; the index error $= +\ 1'\ 40''$; the height of the eye $= 20$ feet. Find the true altitude.

SOLUTION.—

$$\begin{array}{rl}
\text{Jupiter's Obs. Alt. (center)} & = 16^\circ\ 38'\ 30'' \\
\text{I. E.} & = +\quad 1'\ 40'' \\ \hline
 & \ 16^\circ\ 40'\ 10'' \\
\text{Dip} & = -\quad 4'\ 23'' \\ \hline
\text{App. Alt. (center)} & = 16^\circ\ 35'\ 47'' \\
\text{Ref.} & = -\quad 3'\ 9'' \\ \hline
\text{True Alt.} & = 16^\circ\ 32'\ 38''. \text{ Ans.}
\end{array}$$

The parallax of Jupiter being very small, it is disregarded.

EXAMPLE 5.—On December 22, 1898, the observed altitude of Venus's center was $37^\circ\ 43'\ 10''$; the index error $= -\ 1'\ 50''$; the height of the eye $= 22$ feet; the horizontal parallax according to Nautical Almanac $= 27.5$. Find the true altitude.

SOLUTION.—

$$\begin{array}{rl}
\text{Venus's Obs. Alt. (center)} & = 37^\circ\ 43'\ 10'' \\
\text{I. E.} & = -\quad 1'\ 50'' \\ \hline
 & \ 37^\circ\ 41'\ 20'' \\
\text{Dip} & = -\quad 4'\ 36'' \\ \hline
\text{App. Alt. (center)} & = 37^\circ\ 36'\ 44'' \\
\text{Ref.} & = -\quad 1'\ 14'' \\ \hline
 & \ 37^\circ\ 35'\ 30'' \\
\text{Par.} & = +\quad 22'' \\ \hline
\text{True Alt.} & = 37^\circ\ 35'\ 52''. \text{ Ans.}
\end{array}$$

The parallax in altitude is found from the formula of Art. **130;** thus,

$$P.\ A. = H.\ P. \times \cos A.\ A.$$

$$\log 27.5 = 1.43933$$

$$\log \cos 37^\circ\ 35'\ 30'' = 9.89893$$

$$\log P.\ A. = 1.33816$$

$$P.\ A. = 21.7'' \text{ or } 22''$$

This is an extreme case of parallax. For the purpose of practical navigation, the parallax of planets need not be taken into consideration at all. It is shown here how the parallax is obtained for cases where great accuracy is required.

The observed altitude of stars has to be corrected only for index error, if any, dip, and refraction, as shown in the following examples:

Example 6.—The observed altitude of Aldebaran (α Tauri) was 57° 14′ 30″; the index error = + 2′ 20″; the height of the eye = 19 feet. Find the true altitude.

Solution.—

Obs. Alt. ✳	=	57° 14′ 30″
I. E.	= +	2′ 20″
		57° 16′ 50″
Dip	= −	4′ 16″
App. Alt. ✳	=	57° 12′ 34″
Ref.	= −	37″
True Alt.	=	57° 11′ 57″. Ans.

Example 7.—The observed altitude of Regulus (α Leonis) was 38° 10′ 20″; the index error = + 1′ 42″; the height of the eye = 20 feet. Find the true altitude.

Solution.—

Obs. Alt. ✳	=	38° 10′ 20″
I. E.	= +	1′ 42″
		38° 12′ 2″
Dip	= −	4′ 23″
App. Alt. ✳	=	38° 7′ 39″
Ref.	= −	1′ 13″
True Alt.	=	38′ 6′ 26″. Ans.

EXAMPLES FOR PRACTICE

1. The observed altitude of the sun's lower limb was 48° 30′ 15″; the index error = − 2′ 50″; the height of the eye = 15 feet; the semidiameter = 15′ 55″. Find the true altitude. Ans. 48° 38′ 48″

2. The observed altitude of Spica (α Virginis) was 56′ 4′ 40″; the index error = – 3′ 25″; the height of the eye = 28 feet. Find the true altitude. Ans. 55° 55′ 26″

3. The observed altitude of Sirius (α Canis Majoris) was 36° 10′ 20″; the index error = + 2′ 45″; the height of the eye = 20 feet. Find the true altitude. Ans. 36° 7′ 24″

4. The observed altitude of the sun's upper limb was 62° 57′ 40″; the index error = – 3′ 40″; the height of the eye = 24 feet; the semi-diameter = 16′ 6″. Find the true altitude. Ans. 62° 32′ 41″

5. The observed altitude of Mars's center was 31° 40′ 30″; the index error = + 1′ 26″; the height of the eye = 26 feet. Find the true altitude. Ans. 31° 35′ 23″

6. On August 21, 1899, the measured altitude of the sun's lower limb was found to be 43° 22′ 20″; the sextant had no index error; the height of the observer's eye = 30 feet; the semi-diameter = 15′ 51″. What is the sun's true altitude? Ans. 43° 31′ 55″

ARTIFICIAL HORIZON

135. An **artificial horizon**, as its name implies, is a horizon produced by artificial means; and by its use altitudes can be observed when the natural sea horizon cannot be used. This horizon consists of a reflecting surface of some fluid, preferably mercury, in which the image of the object can be seen. The best and most approved kind of artificial

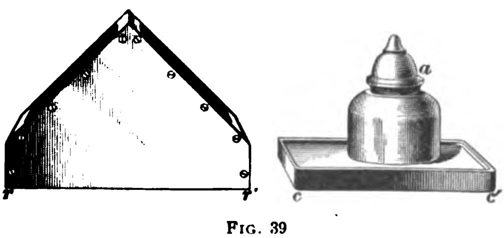


Fig. 39

horizon is that produced by mercury. The implements of a mercurial horizon are shown in Fig. 39. When poured from the bottle *a*, into the shallow basin *c c′*, the mercury by its weight and stability will always preserve an exact horizontal plane at its surface; over the basin is placed a roof *r r′* made of two pieces of plate glass fixed into a frame

that protects the surface from dust and the action of wind. Should mercury not be available, an artificial horizon can be obtained simply by pouring a quantity of oil, tar, or sirup into a shallow vessel, and then preventing the wind from giving a tremulous motion to its surface.

136. How to Measure Altitudes in an Artificial Horizon.—When measuring an altitude, the observer stands at a suitable distance from the basin in order that he may see the image of the celestial object reflected in the mer-

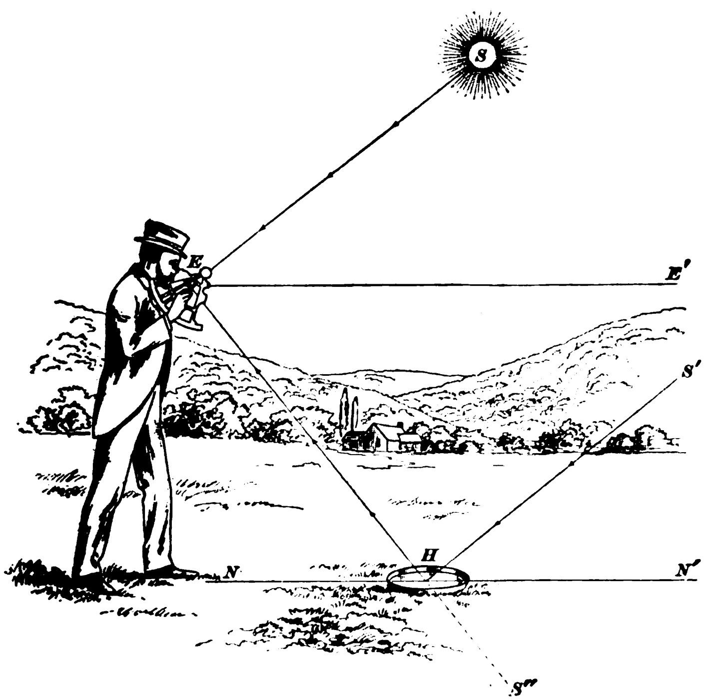


FIG. 40

cury; or, he should seat himself on a low chair with his back supported, if possible, so that the observation can be made with ease and accuracy. Then, with the sextant, he brings down the object until it just touches the reflected object in the basin. The instrumental measure corrected for index

error will then be *double* the apparent altitude of the observed object. By the aid of Fig. 40, this statement may be explained as follows:

The lines SE and $S'H$ that indicate the directions of the rays from the observed body are parallel on account of the distance to the object compared with the distance EH. The altitude of the object is SEE' or $S'HN'$, NN' being the horizontal line. Now, $S'HS''$ is the angle measured, since the object at H will appear to be in the direction EHS''. But, by the law of reflection of light, the angle $S'HN' = EHN = N'HS''$. Hence, the angle measured is *twice* the angle $S'HN'$, or SEE', which is the altitude of the observed body. Consequently, altitudes observed in an artificial horizon must be divided by 2 after being corrected for index error, and no correction for the dip of the horizon has to be applied as in observations made by the sea horizon; but the other corrections must be made as usual. Altitudes measured by means of an artificial horizon are usually known as *double altitudes*.

137. To determine whether the upper or the lower limb of the sun or moon has been measured, reference is made to Fig. 41. Let S represent the reflected image seen direct in the fluid, and S' the reflected image brought down by the sextant. When the edges of these two come into contact, as

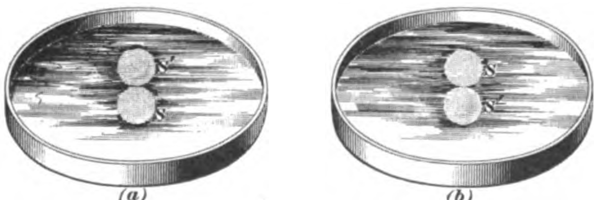


FIG. 41

shown in (a), the lower limb of the sun or moon has been observed, and, consequently, the semi-diameter should be added to the apparent altitude; but, if the upper edge of S' is brought into contact with S, as shown in (b), the upper limb has been observed, and the semi-diameter should then

be subtracted from the apparent altitude in order to obtain the altitude of the center of the observed body.

The foregoing refers to cases where a *direct tube* is used. When using an *inverting tube*, these conditions are changed; then an altitude of the lower limb will appear as shown in (*b*), and of the upper limb as shown in (*a*), Fig. 41. When measuring the altitude of a star by means of an artificial horizon, the two images are simply made to coincide. Altitudes exceeding 60° and less than 15° cannot be measured in an artificial horizon.

138. Correction of Double Altitude.—For correcting altitudes observed in an artificial horizon, the following rule should be followed:

Rule.—*If several altitudes are measured in succession, take the mean of all; apply to this the index error; divide by 2, and apply the other corrections as usual, except that for dip. The result is the true altitude of the observed body.*

EXAMPLE 1.—The following altitudes of the sun's lower limb were observed in succession by means of an artificial horizon: 101° 52′ 40″, 101° 58′ 40″, and 102° 4′ 10″; the index error of the sextant used = − 1′ 50″; the semi-diameter = 15′ 52″. Find the true altitude.

SOLUTION.—	Obs. Alts.	=	101° 52′ 40″
			101° 58′ 40″
			102° 4′ 10″
			3)305° 55′ 30″
	Mean Obs. double Alt. $\underline{\odot}$	=	101° 58′ 30″
	I. E.	=	− 1′ 50″
			2)101° 56′ 40″
	App. Alt. $\underline{\odot}$	=	50° 58′ 20″
	$\odot$ S. D	=	+ 15′ 52″
	App. Alt. $\ominus$	=	51° 14′ 12″
	Ref.	=	− 0′ 46″
			51° 13′ 26″
	$\odot$ Par.	=	+ 0′ 5″
	True Alt.	=	51° 13′ 31″. Ans.

EXAMPLE 2.—On December 20, 1899, using an artificial horizon, the altitude of the sun's upper limb was found to be 28° 58′ 40″; the index error = + 1′ 15″; the semi-diameter according to the Nautical Almanac = 16′ 18″. Find the true altitude.

SOLUTION.—

$$
\begin{aligned}
\text{Obs. double Alt.}\ \overline{\odot} &= 28°\ 58'\ 40'' \\
\text{I. E.} &= +\quad 1'\ 15'' \\
& \ \ 2)\overline{28°\ 59'\ 55''} \\
\text{App. Alt.}\ \overline{\odot} &= 14°\ 29'\ 58'' \\
\odot\ \text{S. D.} &= -\quad 16'\ 18'' \\
\text{App. Alt.}\ \ominus &= 14°\ 13'\ 40'' \\
\text{Ref.} &= -\quad 3'\ 38'' \\
& \quad 14°\ 10'\ \ 2'' \\
\odot\ \text{Par.} &= +\qquad 8'' \\
\text{True Alt.} &= 14°\ 10'\ 10''.\quad \text{Ans.}
\end{aligned}
$$

EXAMPLE 3.—On November 6, 1899, the observed double altitude of the star Vega (*α* Lyræ) was found to be 47° 10′ 50″; the index error = − 0′ 50″. Find the star's true altitude.

SOLUTION.—

$$
\begin{aligned}
\text{Obs. double Alt.}\ \ast &= 47°\ 10'\ 50'' \\
\text{I. E.} &= -\quad 0'\ 50'' \\
& \ \ 2)\overline{47°\ 10'\ \ 0''} \\
\text{App. Alt.}\ \ast &= 23°\ 35'\ \ 0'' \\
\text{Ref.} &= -\quad 2'\ 11'' \\
\text{True Alt.} &= 23°\ 32'\ 49''.\quad \text{Ans.}
\end{aligned}
$$

EXAMPLES FOR PRACTICE

1. On March 14, 1899, the following altitudes of the sun's lower limb were observed in succession by means of an artificial horizon: 84° 25′ 30″, 84° 29′ 20″, 84° 34′ 50″, 84° 40′, and 84° 45′ 10″; the index error of the instrument used = + 3′ 40″; the semi-diameter = 16′ 7″. What is the true altitude? Ans. 42° 34′ 31″

2. The altitude of the star Procyon (*α* Canis Minoris) was measured in an artificial horizon on the evening of September 27, 1899, and was found to be 68° 14′ 20″. The index error of the sextant was − 2′ 20″. Find the star's true altitude. Ans. 34° 4′ 36″

3. The double altitude of the sun's lower limb as measured on a certain day was 106° 21′ 40″. If the index error of the sextant was + 1′ 48″ and the semi-diameter 15′ 58″, what was the corresponding true altitude? Ans. 53° 27′ 4″

NAUTICAL ASTRONOMY

(PART 2)

TIME

MEASUREMENT OF TIME

1. The importance of the accurate determination of time can hardly be overestimated; on it depends the safety of trains on land and of ships at sea. The ordinary method of measuring time is by means of clocks, which are regulated by comparison, directly or indirectly, with the clocks of the great national observatories; these observatory clocks are regulated by means of astronomical observations. To the astronomer, therefore, belongs the duty of the measurement of time on land. At sea, the navigator has a similar duty to perform. In order to determine accurately the position of his ship, he must know the exact local time, and this is obtained only by means of observations of celestial bodies. Hence, the determination of time at sea may be considered as one of the most important problems of nautical astronomy.

2. Culmination, or Transit.—The passage of a celestial body across the observer's meridian is called the *transit*, the *culmination*, or the *meridian passage* of that body. Since a star in its apparent diurnal motion crosses the meridian twice, it is evident that there must be one *upper* and one *lower* transition, the former taking place over that portion of

the meridian which contains the observer's zenith, and the latter over that part containing the observer's nadir. A *day* is defined as the interval of time between two successive upper transits of the same celestial body, and *time* is measured by the hour angle of this body.

3. Classification of Time.—Three distinct kinds of day and three distinct kinds of time are recognized, depending on the celestial body whose transit is selected to determine the day. The three kinds of day are: the *sidereal day*, the *apparent solar day*, and the *mean solar day*. The corresponding kinds of time are: *sidereal time*, *apparent solar time*, and *mean solar time*.

SIDEREAL TIME

4. As defined in *Nautical Astronomy*, Part 1, a *sidereal day* is the period occupied by a fixed star in its apparent revolution about the earth; in other words, a sidereal day is the interval between two successive upper transits of the

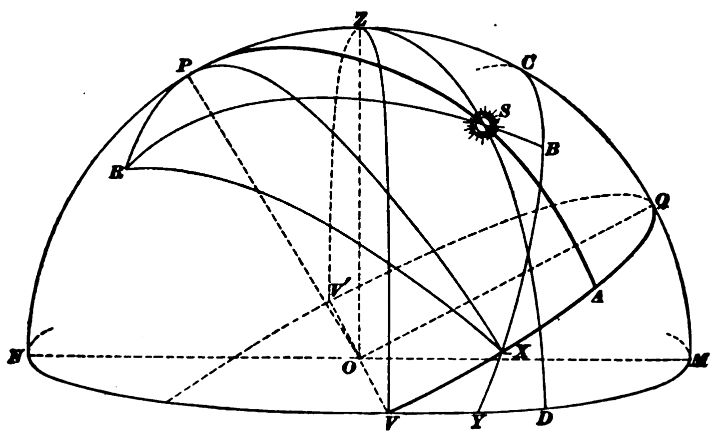


FIG. 1

same fixed star. If the vernal equinoctial point were a fixed point, the interval between two successive upper transits of the vernal equinoctial point would be exactly equal to a sidereal day; but owing to the precession of the equinoxes,

the interval between two successive upper transits of the vernal equinoctial point is less than a true sidereal day by a little less than a one-hundredth part of a second. In practice, this slight difference is neglected and the following definition of a sidereal day is given:

A sidereal day is the interval between two successive upper transits of the vernal equinoctial point, and begins when the vernal equinoctial point is on the meridian.

The difference between the day as determined by the equinoctial point and the true sidereal day amounts to about 1 day in 25,806 years.

5. From Arts. **2** and **3**, it follows that the *sidereal time is the hour angle of the vernal equinoctial point expressed in time.*

The *sidereal clocks* used in observatories show sidereal time. The hands point to $0^h 0^m 0^s$ when the vernal equinoctial point is on the meridian, and the hours are reckoned from 0^h up to 24^h when the vernal equinoctial point is again on the meridian. In Fig. 1, the sidereal time is measured either by the arc XQ of the equator or by the hour angle XPQ.

6. Suppose, in Fig. 1, that a star was in transit; that is, on the meridian between P and M. Then, the right ascension of this star would be the arc XQ.

Hence, *the right ascension of a star, when expressed in time, is equal to the sidereal time of its transit.*

APPARENT SOLAR TIME

7. **Apparent noon** is the time of the sun's upper transit across the meridian; **apparent midnight** is the time of the sun's lower transit across the meridian.

8. An **apparent solar day** is the interval between two successive apparent noons, or between two successive apparent midnights.

9. From Arts. **2** and **3**, it follows that **apparent solar time** *is measured by the sun's hour angle.* Apparent solar

time, or **apparent time,** as it is more commonly known, is the time shown by a sun dial.

10. Relation Between Sidereal and Apparent Time. At noon the sun is on the meridian; hence, according to Art. **6,** *the sidereal time of apparent noon is equal to the sun's right ascension at noon.*

Now, at any instant,

$$\text{sidereal time} = \text{hour angle of } \Upsilon$$
$$\text{apparent solar time} = \text{hour angle of sun}$$

Hence,

$$\text{sidereal time} - \text{apparent solar time} = \text{sun's right ascension}$$

As previously stated, the sun's right ascension is constantly increasing on account of the earth's motion in its orbit. If x represents the sun's increase in right ascension between two successive apparent noons, and the time shown by the sidereal clock at the first noon is 5 P. M., then the sidereal time at the second noon will be $5 + x$ P. M., and the interval between the two noons expressed in sidereal time must be $24^h + x$. That is,

$$\text{apparent solar day} = \text{sidereal day} + x$$

Thus, *the apparent solar day is longer than the sidereal day by the amount of the sun's daily increase in right ascension.*

11. As already stated, the length of the sidereal day is constant. But the sun's daily increase in right ascension is not uniform throughout the year. This want of uniformity is due to two causes: First, in accordance with Kepler's second law, the sun's apparent motion in the ecliptic is not uniform; second, even if the sun did move uniformly in the ecliptic, the increase of its right ascension would not be uniform owing to the inclination of the ecliptic to the equator.

Hence, it follows that the length of the apparent solar day is not the same at all times of the year. For example, December 23 is 51 seconds longer from apparent noon to apparent noon than September 16.

MEAN SOLAR TIME

12. Disadvantage of Sidereal Time.—The sidereal time of apparent noon on any day is equal to the sun's right ascension on that day, and, consequently, it gets later by 24 hours during the year. Thus, the sidereal time of apparent noon on March 21 is 0^h; on June 21 is 6^h; on September 23 is 12^h; on December 22 is 18^h.

It will be seen, then, that sidereal time bears no simple relation to the phenomena of day and night, and is therefore unsuitable for every-day use.

13. Mean Sun.—As already explained, the length of the apparent solar day is not the same at all times of the year and cannot therefore be measured by a clock having a uniform rate. In order to overcome this irregularity arising from using the true sun as a measure of time, a fictitious sun, called the **mean sun,** has been adopted, which is assumed to move along the celestial equator with a uniform velocity. This mean sun is supposed to keep on the average as near the real sun as is consistent with perfect uniformity of motion, sometimes in advance and sometimes behind the true sun, the greatest deviation between the two being about 16 minutes of time. It must be borne in mind, however, that the mean sun is not a body of any kind, but merely an imaginary point that is supposed to move uniformly around the celestial equator in the same time the true sun takes to move around the ecliptic.

14. Mean time, which is perfectly equable in its increase, is measured by the motion of this mean sun. Clocks in ordinary use are regulated to indicate mean time.

15. Mean Solar Day.—The interval of time between two successive mean noons is called a **mean solar day;** it is the average, or mean, of all the apparent solar days in a year. The mean solar day is divided into 24 intervals, called **hours,** of mean time. Mean time, or mean solar time, is measured by the hour angle of the mean sun.

16. Equation of Time.—The difference between mean and apparent time at any instant is called the **equation of time,** and this difference may amount to as much as 16 minutes and 21 seconds. By means of the equation of time, apparent time may be changed to mean time, or the reverse, by adding or subtracting it according to directions given in the Nautical Almanac, where its value is recorded for every day of the year. By examining the abridgment of the Nautical Almanac accompanying this Section, it will be seen that at four times during the year the equation of time is zero—April 15, June 14, September 1, and December 25. This shows that the equation of time is a variable quantity caused by the true sun being alternately ahead of and behind the mean sun. From December 23 to April 15, the true sun is in advance of the mean sun; and from the latter date to June 14, it is behind the mean sun. During the period from June 14 to August 31, the true sun is ahead of, and from August 31 to December 24 it is behind the mean sun.

17. Astronomical Day.—When mean time is used in astronomical work, the day begins at mean noon and is called the **astronomical day;** astronomical mean time is reckoned continuously up to 24 hours.

18. Civil Day.—When mean time is used in the ordinary affairs of life, it is called **civil time,** and the civil day begins at midnight, 12 hours earlier than the astronomical day. Thus, January 9, 2^h A. M., civil time, is January 8, 14 hours, astronomical time; and January 9, 2^h P. M., civil time, is January 9, 2 hours, astronomical time. It may be noted here that A. M. signifies *in the morning* (*ante meridiem*), and P. M. means *in the afternoon* (*post meridiem*).

19. To Convert Civil Into Astronomical Time.—If the given time is A. M., deduct 1 from the date, add 12 hours, and omit the A. M.; if the given time is P. M., simply omit the P. M. The result in both cases is the required astronomical time. Thus, July 1, $11^h\ 8^m\ 25^s$ A. M., civil time, is June 30, $23^h\ 8^m\ 25^s$, astronomical time; and March 2, $11^h\ 15^m\ 32^s$ P. M., civil time, is March 2, $11^h\ 15^m\ 32^s$, astronomical time.

20. To Convert Astronomical Into Civil Time.—If the hours of the given time are less than 12, simply affix P. M.; if greater than 12, subtract 12, increase the date by 1, and affix A. M. Thus, February 2, $8^h\ 4^m\ 30^s$, astronomical time, is February 2, $8^h\ 4^m\ 30^s$ P. M., civil time; and December 31, 15^h, astronomical time, is January 1, 3^h A. M., civil time.

21. Local mean time is the mean time at a certain place or locality, as, for example, the mean time at ship. At no instant can the mean time be the same at two places unless they are situated on the same meridian.

22. Standard Time.—The United States, extending from 65° to 125° west longitude, is divided into four *time sections*, each section consisting of 15° of longitude, which is equivalent to 1 hour of time. The time officially recognized in each of these sections is known as the **standard time.** The meridians adopted to serve as the center line of each section are the 75th, 90th, 105th, and 120th. Hence, the local mean time of each meridian is supposed to be used for a distance of $7\frac{1}{2}°$ of longitude on each side of it, although in practice the boundary lines between the sections are rather irregular. How these time sections are denoted is seen from the following:

Standard
- *Eastern time* corresponds to the 75th meridian.
- *Central time* corresponds to the 90th meridian.
- *Mountain time* corresponds to the 105th meridian.
- *Pacific time* corresponds to the 120th meridian.

Owing to this simple arrangement, it follows that when it is 11^h A. M. by eastern time at New York, for instance, it is 10^h A. M. by central time at Chicago, 9^h A. M. by mountain time at Denver, and 8^h A. M. by Pacific time at San Francisco.

In Fig. 2 are shown the meridians whose time is used in the different time sections. The dotted, irregular lines indicate approximately the boundaries of each section, and show the localities of the United States and Canada in which these several kinds of time are used. Standard time is sent daily from the Naval Observatory at Washington D. C., to


PACIFIC TIME
MOUNTAIN TIME
CENTRAL TIME
EASTERN TIME
120°
105°
90°
75°
45°
35°
25°
James Bay
Kamloops
Calgary
Prince Albert
Spokane
Tacoma
Winnipeg
Port Arthur
White River
Chatham
Quebec
Portland
Walla Walla
Helena
Miles City
Bismarck
Duluth
Marquette
Sault Ste. Marie
Montreal
Halifax
Boise
Alpena
Portland
Eureka
Pocatello
Lander
Pierre
St. Paul
Albany
Boston
Cheyenne
Sioux City
Milwaukee
Detroit
Buffalo
Carson City
Salt Lake City
North Platte
Des Moines
Omaha
Chicago
Toledo
New York
San Francisco
Frisco
Cleveland
Pittsburg
Grand Junction
Denver
Springfield
Columbus
Independence
Pueblo
Hannibal
Indianapolis
WASHINGTON
Kansas City
St.Louis
Lexington
Richmond
Wichita
Los Angeles
Flagstaff
Santa Fe
Oklahoma
Nashville
Knoxville
Raleigh
Phenix
Wilmington
Little Rock
Memphis
Atlanta
Augusta
Ft.Worth
El Paso
Vicksburg
Shreveport
Montgomery
San Antonio
New Orleans
Galveston
Tampa
GULF OF MEXICO
Key West
PACIFIC OCEAN
ATLANTIC OCEAN
8 HOURS
(8 A.M.)
SCALE OF MILES
100 50 0 100 200 300 400
7 HOURS
(9 A.M.)
6 HOURS
(10 A.M.)
5 HOURS
(11 A.M.)

FIG. 2

the more important telegraph offices of the United States, and thus serves to regulate clocks and watches to the almost complete exclusion of local time.

23. To Convert Standard Time Into Local Time. In order to find the correct local time of a place from the reading of a clock set to standard time, a correction must be applied. The amount of this correction will depend on the longitude of the observer, and must be either added to or subtracted from the time indicated by the clock, at the rate of 4 minutes for every degree of longitude the observer is to the east or west of the meridian used. Thus, if the longitude of the observer is 80° W and his clock shows the time of the 75th meridian, or eastern time, he is 5° to the west of that meridian, and must therefore subtract $5 \times 4 = 20$ minutes from the time shown by the clock to find the corresponding local mean time; if he had been in longitude 70° W, or 5° to the east of the 75th meridian it would have been necessary to add $5 \times 4 = 20$ minutes to the clock time in order to obtain the local mean time. Or, if the observer's clock shows the time of the 120th meridian, or Pacific time, and he is in longitude 126° 30′ W, he is 6.5° to the west of the 120th meridian, and must subtract $6.5 \times 4 = 26$ minutes from the time shown by the clock; but if his longitude had been 113° 30′ W, or 6.5° to the east of the 120th meridian, it would have been necessary to add 26 minutes to the time shown by the clock in order to obtain his local mean time.

THE CALENDAR

24. A **year** is defined as the period of a complete revolution of the sun in the ecliptic. In order, however, to complete this definition, it is necessary to specify the starting point from which the revolution is measured. By taking different starting points, different kinds of years result.

25. Tropical Year.—A **tropical year** is the interval of time between two successive passages of the sun through the vernal equinoctial point. The length of a tropical year

at the present time is very approximately $365^d\ 5^h\ 48^m\ 46.51^s$ of mean time.

26. Sidereal Year.—A **sidereal year** is the period of a complete revolution of the sun, starting from and returning to the same fixed point among the constellations. If the vernal equinoctial point were a fixed point, the tropical year and the sidereal year would be the same. But the vernal equinoctial point has a retrograde motion, completing the circuit of the ecliptic in about 25,868 years; therefore, its retrograde motion amounts to about $360° \div 25{,}868 = 50.1''$ in a year. This causes the vernal equinox to happen earlier than it otherwise would by an interval of about 20 minutes. Therefore, the tropical year is 20 minutes shorter than the sidereal year.

27. Civil Year.—For ordinary purposes, it is important that the year should contain an exact number of days and also bear a simple relation to the recurrence of the seasons. Neither the sidereal nor the tropical year contains an exact number of days. The sidereal year has the additional disadvantage of not marking the recurrence of the seasons.

For these reasons the **civil year** has been introduced, the length of which is sometimes 365 days and sometimes 366 days. The Roman emperor Julius Cæsar ordered that three successive years should have 365 days each, and the fourth year, 366 days. The fourth year, which contains 366 days, is called a *leap year*, and the calendar constructed on this principle is called the *Julian calendar*. For convenience, the leap years are those whose number is exactly divisible by 4; as 1684, 1872, etc.

A simple arithmetical calculation shows that three ordinary years and one leap year exceed four tropical years by $44^m\ 57.96^s$. Therefore, 400 years of the Julian calendar exceed 400 tropical years by $3^d\ 2^h\ 56^m\ 36^s$. In order to remedy errors accumulated by this arrangement, Pope Gregory XIII, in 1582, amended the Julian calendar by omitting three days in every four centuries, and ordered that: Every year whose number is a multiple of 100 shall

be an ordinary year of 365 days, unless the number of the year is divisible by 400, in which case the year is a leap year.

The calendar constructed in accordance with this correction is called the *Gregorian calendar.* The error in the Gregorian calendar is very small and will not amount to more than $1^d\ 5^h\ 30^m$ in 4,000 years.

In the Gregorian calendar, the year 1900 was not a leap year, because the number 1900 was not exactly divisible by 400; but the year 2000 will be a leap year, because 2000 is exactly divisible by 400. The Gregorian calendar is now adopted by all nations except Russia.

28. Old Style and New Style.—At the time of the Council at Nice (325 A. D.), the sun was in the vernal equinoctial point on March 21, by the Julian calendar; in 1582 the sun was at the same point on March 11. Pope Gregory therefore, in correcting the calendar, ordered that the day after October 4, 1582, should be called October 15, 1582.

In England, the Gregorian calendar was not adopted until the year 1752, when the error of the Julian calendar amounted to 11 days. In 1751 the English Parliament enacted that the day after September 2, 1752, should be called September 14, 1752.

During the period immediately following the adoption of the Gregorian calendar, to avoid confusion, writers usually specified whether their dates were given in **old style** (according to the Julian calendar) or in **new style** (according to the Gregorian calendar). Thus, January 4, 1626, O. S., means January 4, 1626, of the Julian calendar.

THE CHRONOMETER

29. Important Function of the Chronometer.—It has been pointed out that the difference between the local time of any place on the earth's surface and the local time of Greenwich, expressed in degrees and fractions, is equal to the longitude of that place. If, therefore, a navigator knows his own local time and that of Greenwich at the

same instant, it is evident that by comparing these times he is at once enabled to ascertain the longitude of his ship. The question that naturally arises then is this: How may one find his local time and the time at Greenwich in order to compare them?

The local time of the ship, or of any other place, is found by means of observation of celestial bodies, according to methods to be described hereafter, and the Greenwich time is found by a very accurate timepiece, called the **chronometer,** which is carried with the ship and therefore available at all times. Hence, the principal reason for supplying a ship with chronometers is to facilitate the determination of the ship's longitude.

30. Characteristic Features of the Chronometer. As previously stated, the chronometer is a very accurate watch, and, as such, is the product of the highest excellency in workmanship and material. The chronometer is set to indicate Greenwich mean time, and by allowing for its gaining or losing, the navigator has the Greenwich time itself with an accuracy that depends only on the uniformity with which the chronometer works. It makes no difference to what extent the chronometer either gains or loses time, provided its daily rate of motion is uniform.

The mechanical construction and adjustment of a chronometer do not enter into the study of navigation; all that is required of a navigator is to know *how to take care of it, how to investigate its error,* and *how to properly allow for this error.*

31. Like a compass, the chronometer is placed in a box and swung in gimbals (see Fig. 3) to preserve its horizontal position and to prevent it from being injured by the motion of the ship. Also, in order that changes of temperature likely to be met with on a voyage shall have the least possible effect on its mechanism, all chronometers are fitted with a *compensation balance* that is so constructed that the rate of losing or gaining is made approximately uniform at all temperatures.

Some chronometers are constructed to run 2 days, others 8 days. The former are wound daily, and the latter every seventh day, so that in case the winding should be forgotten for 24 hours the chronometer will still be found running. It is important, however, to wind chronometers at stated inter-

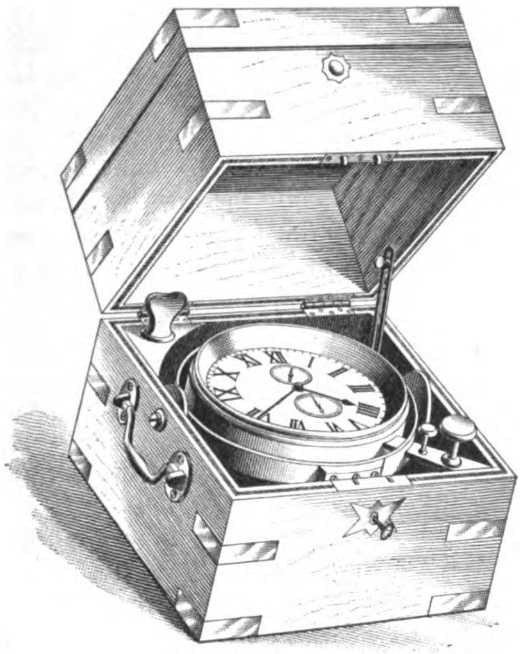


FIG. 8

vals; otherwise, an unused part of the spring comes into action and an irregularity in the rate may result.

The following instructions relating to the management of chronometers are recommended by makers and other authorities on this subject.

32. How to Wind a Chronometer.—When winding a chronometer, slowly turn over the chronometer bowl in its gimbals with the left hand; slide the valve, by pressing the forefinger of the left hand against the nail piece on the valve, until the keyhole is uncovered; insert the winding key with

the right hand, and wind to the left until a decided stop is felt. After removing the key, do not let the chronometer drop to its level of its own accord, but carefully let it down until it rests in a horizontal position. The winding should be performed with a given number of half turns of the key. It is well to know this number and to count when winding, so as to avoid a sudden jerk at the last turn.

33. When a chronometer has stopped, it will not start to run immediately after being wound. It is necessary to give the whole instrument a quick rotary movement, by which the balance wheel is set in motion. This must be done with care, however, and with no more force than is necessary to produce the result. The hands of the chronometer can be moved without injury to the instrument, so that it may be set approximately to the correct time; but, it is better to wait until the hands indicate the proper time and then start the instrument in the manner described.

34. Placing a Chronometer.—Chronometers should be placed on board ship as near the center of motion as possible, and should be stowed in boxes made especially for this purpose. The sides and bottom of these boxes must be padded or lined with soft cushions, so that the instruments may be tightly wedged in and the effects of vibration and concussion minimized. The temperature of the room wherein chronometers are placed should not be subjected to sudden changes, but should be kept as uniform as possible, the proper temperature being about 70° F. The chronometer, after being placed in position, should be allowed to swing freely in its gimbals, so as to preserve a horizontal position. In a very damp or moist climate, it is advisable to wrap a blanket around the outside case of the instrument to preserve its dryness. On no account should chronometers be taken from their outside cases for deck observations; for such purpose, a comparing watch should be used. The place selected for a chronometer should be absolutely free from the proximity of iron, electric dynamos, electric wiring, and the magnetic influence of the compass and compensation

magnets. Too much cannot be done to protect a chronometer from rust; a small spot may at times seriously interfere with the rate of the instrument.

35. Transportation of Chronometers.—As the chronometer is a most delicate instrument, great care should be taken when transporting it to avoid sudden jerks and vibrations. If taken from one place to another, whether carrying it by hand or otherwise, the instrument should not be allowed to swing in its gimbals; it should be fastened by the clamp provided for this purpose. When transported by rail, for instance, the instrument case and its casing should be placed in a basket or other suitable substitute, well padded with cotton or other soft substances so as to keep it from jarring.

36. Cleaning.—Chronometers should be cleaned and oiled every $3\frac{1}{2}$ years, or sooner if they show unsteadiness in their rates, having previously been regular. There are many cases of chronometers performing well for 5 and 6 years, or even longer, without cleaning or oiling, but such cases are exceptional and therefore this fact should not be thought to establish a rule. When in need of cleaning and oiling, the chronometer should be sent to a reliable instrument maker, preferably the one by whom it was made.

RATING THE CHRONOMETER

37. A chronometer, however well it may be constructed, is never perfect; it either gains or loses, and the amount of this gain or loss per day is called the **daily rate.**

The daily rate is furnished by the dealer that delivers the instrument, or by the observatory or other authority to which it has been sent for rating. The rate is usually in the form of a written statement, which says that on such and such a date the chronometer was so many minutes and seconds faster or slower than Greenwich mean time, and is *losing or gaining a certain amount each day*. The statement that on a certain date the instrument is faster or slower than Greenwich mean time, is conveniently termed the **original error.**

38. Application of Error and Daily Rate.—It is evident that in order to find the correct Greenwich mean time, the navigator must apply to the time shown by the chronometer, first, the original error according to its sign, and then the daily rate multiplied by the number of days elapsed since the original error was determined. The rule to be remembered when applying these data is as follows:

Rule.—I. *The original error is* **subtractive** (−) *if the chronometer has been found* **fast,** *and* **additive** (+) *if found* **slow** *on Greenwich mean time.*

II. *The product of the daily rate (assumed to be uniform) multiplied by the number of days elapsed is* **subtractive** (−) *if the chronometer is gaining, and* **additive** (+) *if losing.*

Example 1.—On May 19, P. M., 1899, the chronometer indicated $6^h\ 59^m\ 42^s$. The original error on May 1, Greenwich mean noon, was $3^m\ 18^s$ fast; daily rate = 7.8^s gaining. Find the correct Greenwich mean time (G. M. T.) on May 19.

Solution.—First find the accumulated gain by multiplying the daily rate by the number of days and fraction elapsed since the original error was determined. Thus,

$$\begin{array}{rr}
\text{Daily rate (gaining)} = & 7.8^s \\
\text{Days elapsed, May 1 to May 19} = & \underline{\times\ 18} \\
 & 624 \\
 & \underline{78} \\
 & 60)\overline{140.4^s} \\
\text{Gain in 18 da.} = & 2^m\ 20.4^s \\
\text{Gain in } 6^h\ 59^m\ 42^s\text{, or 7 hr.} = \dfrac{7.8 \times 7}{24} = & \underline{+\quad 2.3^s} \text{ (nearly)} \\
\text{Accumulated gain} = & 2^m\ 22.7^s
\end{array}$$

Then, in order to find the required correct G. M. T., apply the rules just given. Thus,

$$\begin{array}{rl}
\text{Chron.} = & 6^h\ 59^m\ 42^s \\
\text{Original error (fast)} = & \underline{-\quad 3^m\ 18^s} \\
 & 6^h\ 56^m\ 24^s \\
\text{Accumulated gain} = & \underline{-\quad 2^m\ 22.7^s} \\
\text{Corr. G. M. T., May 19} = & 6^h\ 54^m\ \ 1.3^s. \quad \text{Ans.}
\end{array}$$

Example 2.—On April 15, the chronometer showed $1^h\ 25^m\ 27^s$; the original error as determined on April 5 was $3^m\ 20^s$ slow on Greenwich mean time; daily rate = $.8^s$ losing. Find the correct Greenwich mean time.

SOLUTION.—

$$\begin{array}{rl} \text{Daily rate (losing)} = & .8^s \\ \text{Days elapsed, Apr. 5 to Apr. 15} = & 10 \\ \hline \text{Loss in 10 da.} = & 8^s \end{array}$$

$$\begin{array}{rl} \text{Chron.} = & 1^h\ 25^m\ 27^s \\ \text{Original error (slow)} = & +\ 3^m\ 20^s \\ \hline & 1^h\ 28^m\ 47^s \\ \text{Accumulated loss} = & +\ 8^s \\ \hline \text{Corr. G. M. T.} = & 1^h\ 28^m\ 55^s. \quad \text{Ans.} \end{array}$$

39. To Find the Daily Rate.—When, by one means or another, the error of a chronometer on Greenwich mean time for two different dates is obtained, the daily rate of the chronometer may be found by dividing the sum or difference of these errors by the number of days elapsed between the two dates.

The errors are written one under the other, and if both are slow or both fast, their difference is taken; but if one is slow and the other fast, their sum is taken.

EXAMPLE 1.—On January 1, 1899, at Greenwich mean noon, a chronometer was found to be $1^m\ 42^s$ slow, and on March 31 at mean noon it was $6^m\ 9^s$ slow. Find the daily rate.

SOLUTION.—

$$\begin{array}{rl} \text{Error, Jan. 1} = & 1^m\ 42^s \text{ slow} \\ \text{Error, Mch. 31} = & 6^m\ 9^s \text{ slow} \\ \hline \text{Difference} = & 4^m\ 27^s \\ \text{Or} = & 267^s \end{array} \qquad \begin{array}{rr} & \text{Jan. } 30 \\ & \text{Feb. } 28 \\ & \text{Mch. } 31 \\ \hline \text{Days elapsed} = & 89 \end{array}$$

$$\text{Daily rate} = \frac{267}{89} = 3^s \textit{ losing}. \quad \text{Ans.}$$

In this case, it is evident that since the first error is slow and the second still slower, the rate is *losing*.

EXAMPLE 2.—On June 1, 1899, a chronometer was found to be $1^m\ 8.8^s$ slow, and on September 30 it was 40.1^s fast. Find the daily rate.

SOLUTION.—

$$\begin{array}{rl} \text{Error, June 1} = & 1^m\ 8.8^s \text{ slow} \\ \text{Error, Sept. 30} = & 0^m\ 40.1^s \text{ fast} \\ \hline \text{Sum} = & 1^m\ 48.9^s = 108.9^s \end{array} \qquad \begin{array}{rr} & \text{June } 29 \\ & \text{July } 31 \\ & \text{Aug. } 31 \\ & \text{Sept. } 30 \\ \hline \text{Days elapsed} = & 121 \end{array}$$

$$\text{Daily rate} = \frac{108.9}{121} = .9^s \textit{ gaining}. \quad \text{Ans.}$$

EXAMPLE 3.—On January 14, 1900, a chronometer was found to be $2^m\ 17^s$ fast, and on June 1 it was $3^m\ 55.5^s$ slow. What is the daily rate?

SOLUTION.—

Error, Jan. 14 = $2^m\ 17^s$ fast		Jan. 17
Error, June 1 = $3^m\ 55.5^s$ slow		Feb. 28
Sum = $6^m\ 12.5^s = 372.5^s$		Mch. 31
		Apr. 30
		May 31
		June 1
	Days elapsed =	138

$$\text{Daily rate} = \frac{372.5}{138} = 2.7^s \textit{ losing}. \quad \text{Ans.}$$

EXAMPLE 4.—On February 24, 1900, a chronometer showed $1^h\ 12^m\ 20.5^s$. By observations taken on October 30, 1899, it was found to be $13^m\ 35^s$ slow, and on December 24, 1899, $10^m\ 55.5^s$ slow. Find the correct Greenwich mean time.

SOLUTION.—In this case, the daily rate must be determined first. Thus,

Error, Oct. 30 = $13^m\ 35^s$ slow		Oct. 1
Error, Dec. 24 = $10^m\ 55.5^s$ slow		Nov. 30
Difference = $2^m\ 39.5^s = 159.5^s$		Dec. 24
	Days elapsed =	55

$$\text{Daily rate} = \frac{159.5}{55} = 2.9^s \textit{ gaining}$$

$$\begin{array}{rl}
\text{Daily rate (gaining)} = & 2.9^s \\
\text{Days elapsed, Dec. 24 to Feb. 24} = & \times\ 62 \\
\hline
& 58 \\
& 174 \\
\hline
\text{Accumulated gain} = & 179.8^s = 2^m\ 59.8^s
\end{array}$$

$$\begin{array}{rl}
\text{Chron., Feb. 24} = & 1^h\ 12^m\ 20.5^s \\
\text{Original error, Dec. 24 (slow)} = & +\ 10^m\ 55.5^s \\
\hline
& 1^h\ 23^m\ 16^s \\
\text{Accumulated gain} = & -\ \ 2^m\ 59.8^s \\
\hline
\text{Corr. G. M. T.} = & 1^h\ 20^m\ 16.2^s. \quad \text{Ans.}
\end{array}$$

NOTE.—In the illustrative examples given, as well as in the Examples for Practice that follow, the errors are assumed to be determined for mean noon at Greenwich, and the observations for rate to be taken at the same place.

EXAMPLES FOR PRACTICE

1. On August 28, 1900, a chronometer was found to be $7^m\ 2.1^s$ fast, and on December 9, 1900, it was $2^m\ 24^s$ fast. Find the daily rate.
Ans. 2.7^s *losing*

2. On January 14, 1899, a chronometer was found to be $3^m\ 20^s$ slow, and on May 14 it was $2^m\ 40^s$ fast. What is the daily rate?
Ans. 3^s *gaining*

3. On December 4, a chronometer indicated $1^h\ 0^m\ 42^s$. On June 1 it was found to be 12^s slow; but on July 1 it was $4^m\ 27^s$ fast. Find: (*a*) the correct Greenwich mean time on December 4, and (*b*) the daily rate of the chronometer.
Ans. $\begin{cases} (a)\ 0^h\ 32^m\ 4.2^s \\ (b)\ 9.3^s \textit{ gaining} \end{cases}$

COMPARISON OF CHRONOMETERS

40. Ships destined for long voyages should, as a rule, carry three chronometers. One of the instruments—the best, as nearly as can be judged—is then selected as the standard, and with this the others are compared daily *after* winding. The record made of these comparisons will show the relative performances of each chronometer.

The operation of comparing chronometers should be performed by one person without assistance. This may at first appear difficult, but after practicing a week or two it may be done very readily.

41. Method of Comparison.—Denote the standard chronometer by A and the others by B and C, respectively. Close all windows and doors leading to the chronometer room. This will shut off the noise from outside and enable the observer to hear the beats of the three chronometers. Now, with pencil and pad in hand, take a position between the chronometers A and B, so that the dials of both can be seen. Open the glass top of A; this will make the beats of A more distinctly heard than those of B or C. Decide for an even minute on the chronometer A and write this down; for example, $8^h\ 56^m\ 0^s$. Looking at the dial of A, begin to count, mentally, the seconds when the chronometer indicates $8^h\ 55^m\ 40^s$; thus *one*, *and two*, *and three*, *and four*, so that the word "and" comes on every half second. At 50^s count ten

and recommence by *and one*, *and two*, *and three*, etc. When 53^s or 54^s is reached, turn the eyes to chronometer *B*, counting in the same order by the beats of *A*. When the 60th second is counted, the observer should be able to estimate how many seconds and the fraction of a second *B* indicates. This marked down, compare *A* and *C* in a similar manner after an interval of 2 or 3 minutes. Mark down the result, and subtract from it the number of minutes in the interval. This will give the reading of chronometer *C* at the moment when *A* indicated $8^h\ 56^m\ 0^s$. To make sure that the results obtained are correct, repeat the whole operation once or twice.

42. Chauvenet recommends that "each chronometer should be accompanied with a record from a responsible maker, or, better still, from an observatory, showing the daily rates for mean temperature for each 10°, say from 40° to 100° F.; then, with a maximum and minimum thermometer in the chronometer case, the actual temperature of the preceding day is recorded as soon as the case is opened for winding in the morning. Then, by referring to the tabulated record of observed daily rates according to temperature, the rate for the preceding day is found by inspection, and, applying this according to its sign to the sum of the accumulated daily rates up to the previous day, there will be found the whole amount of the accumulated rate on the given day to be applied as a correction to the original error. Although the rates may differ with lapse of time, etc., it is more likely that the differences of rates for corresponding temperatures will remain the same or nearly so."

43. Where a ship is provided with only one chronometer, any comparisons are out of the question. The navigator should then avail himself of every opportunity presented to determine the error and rate of his chronometer according to methods that will be given hereafter. Until such new error and rate is found, the navigator should use the error and rate as furnished by the maker in conjunction with a correction for the temperature as mentioned in Art. **42.** However, when navigating in the temperate or the torrid

zones, the correction for temperature can be neglected; it is only in unusual cases, for instance when the chronometer has been exposed to great extremes of heat or cold for a considerable time, that this correction need be taken into consideration.

44. The disadvantage of having two chronometers is evident from the fact that, should they show any marked difference after having been regular, the navigator is unable to tell which of the instruments is faulty. The only advantage gained by carrying two chronometers is that one will serve as a substitute should the other get entirely out of order.

THE NAUTICAL ALMANAC

EXPLANATION OF ITS CONTENTS

45. The **Nautical Almanac** is a publication prepared and issued by the government for the use of navigators and others. It contains all the astronomical elements necessary for the determination of latitude and longitude at sea. How these elements are picked out and utilized will be shown in the various calculations throughout this Section.

46. The first part of the Nautical Almanac is especially important to the navigator. Data relating to the sun are to be found on the first and second pages of each month; those of the moon, on the fourth and subsequent pages. Exact reproductions of the first two pages of the Almanac are shown herewith; of these, page I contains the data for *apparent time* and page II the data for *mean time*. Hence, when dealing with apparent time, turn to the former, and when dealing with mean time, to the latter.

47. **The Greenwich Date.**—Since all data in the Nautical Almanac are given for Greenwich time, it is evident that an observer at any other place must reduce his local time to that of Greenwich, in order to obtain the value of the required quantity corresponding to his local time. In

JANUARY, 1899

AT GREENWICH APPARENT NOON I

Day of the Week	Day of the Month	The Sun's Apparent Right Ascension	Diff. for 1 Hr.	Apparent Declination	Diff. for 1 Hr.	Semi-Diameter	Sidereal Time of Semi-Diameter Passing Meridian	Equation of Time, to be Added to Apparent Time	Diff. for 1 Hr.
		h m s	s	° ′ ″	″	′ ″	s	m s	s
Sun.	1	18 47 28.68	11.037	S 23 0 14.0	+12.52	16 18.40	71.04	3 47.32	1.178
Mon.	2	18 51 53.43	11.024	22 54 59.9	13.66	16 18.39	71.00	4 15.43	1.165
Tues.	3	18 56 17.85	11.010	22 49 18.3	14.80	16 18.38	70.95	4 43.21	1.150
Wed.	4	19 0 41.89	10.994	22 43 9.5	+15.93	16 18.36	70.90	5 10.63	1.134
Thur.	5	19 5 5.55	10.977	22 36 33.6	17.06	16 18.34	70.84	5 37.65	1.117
Fri.	6	19 9 28.77	10.959	22 29 30.7	18.17	16 18.31	70.78	6 4.24	1.099

other words, he must find the **Greenwich date** (G. D.); that is, the date, hour, minute, and second, corresponding to his own local time. *This is done by applying to the local time the longitude of the observer reduced to time, adding if the longitude is west, and subtracting if the longitude is east.* As the Greenwich date should be expressed in astronomical time, it is necessary to convert the local (civil) time to astronomical before applying the longitude.

EXAMPLE 1.—On March 27, 1900, in longitude 45° 45′ W, the local time according to the ship's clock is $4^h\ 30^m$ A. M.; what is the corresponding time at Greenwich, or the Greenwich date?

SOLUTION.— Time at ship, Mch. 27 = $4^h\ 30^m$ A. M.
Or, Ast. time, Mch. 26 = $16^h\ 30^m$
Long. (W) in time = $+\ 3^h\ \ 3^m$
G. D., Mch. 26 = $19^h\ 33^m$

Hence, the time at Greenwich corresponding to Mch. 27, $4^h\ 30^m$ A. M., in longitude 45° 45′ W, is Mch. 26, $19^h\ 33^m$. Ans.

EXAMPLE 2.—Find the Greenwich date corresponding to $10^h\ 35^m$ P. M., January 21, 1900, local time, in longitude 43° E.

SOLUTION.— Local time, Jan. 21 = $10^h\ 35^m$
Long. (E) in time = $-\ \ 2^h\ 52^m$
G. D., Jan. 21 = $7^h\ 43^m$. Ans.

EXAMPLE 3.—On November 6, 1900, in longitude 117° E, the local time is $2^h\ 15^m$ P. M. Find the corresponding Greenwich date?

JANUARY, 1899

II AT GREENWICH MEAN NOON

Day of the Week	Day of the Month	The Sun's Apparent Right Ascension	The Sun's Diff. for 1 Hr.	The Sun's Apparent Declination	The Sun's Diff. for 1 Hr.	Equation of Time, to be Subtracted From Mean Time	Diff. for 1 Hr.	Sidereal Time, or Right Ascension of Mean Sun
		h m s	s	° ′ ″	″	m s	s	h m s
Sun.	1	18 47 27.98	11.034	S 23 0 14.9	+12.51	3 47.24	1.178	18 43 40.74
Mon.	2	18 51 52.65	11.021	22 55 0.9	13.65	4 15.34	1.164	18 47 37.30
Tues.	3	18 56 16.98	11.006	22 49 19.5	14.79	4 43.12	1.150	18 51 33.86
Wed.	4	19 0 40.94	10.990	22 43 10.9	+15.92	5 10.53	1.134	18 55 30.42
Thur.	5	19 5 4.52	10.973	22 36 35.2	17.05	5 37.54	1.117	18 59 26.97
Fri.	6	19 9 27.66	10.955	22 29 32.6	18.16	6 4.13	1.099	19 3 23.53

SOLUTION.— Local time, Nov. 6 = $2^h\ 15^m$ P. M.

Or, Nov. 5 = $26^h\ 15^m$

Long. (E) in time = $-\ 7^h\ 48^m$

G. D., Nov. 5 = $18^h\ 27^m$

In this case, the longitude to be subtracted being greater than the local time, it is necessary to add 24^h and put the date back 1 da.; this gives Nov. 5, $26^h\ 15^m$ as local time and the G. D. as Nov. 5, $18^h\ 27^m$. Ans.

48. The Greenwich time corresponding to the ship's time may, of course, be taken directly from the chronometer; but since the dial of a chronometer is marked up to 12 hours only, this may lead to a mistake in determining the date. This is especially true when the longitude is large. In such cases, it is advisable to get an approximate value of the Greenwich date, as shown in the preceding examples, and then, in cases where the difference between this approximation and the time indicated by the chronometer is nearly 12 hours, to add 12 hours to the reading and put the date back 1 day, if necessary, as shown in the following examples:

EXAMPLE 1.—The local time at ship in longitude 150° 30′ W is, October 22, $5^h\ 40^m$ P. M.; at that time the chronometer indicated $3^h\ 22^m\ 10^s$, its error on Greenwich mean time being $10^m\ 50^s$ slow. Find the Greenwich date.

SOLUTION.— Ship's time, Oct. 22 = $5^h\ 40^m$

Long. (W) in time = $+\ 10^h\ \ 2^m$

Approx. G. D., Oct. 22 = $15^h\ 42^m$

$$
\begin{array}{rl}
\text{Chronometer} = & 3^h\ 22^m\ 10^s \\
\text{Error (slow)} = & +\ \ 10^m\ 50^s \\
\hline
 & 3^h\ 33^m\ 0^s \\
 & +\ 12^h\ 0^m\ 0^s \\
\hline
\text{G. M. T., or G. D., Oct. 22} = & 15^h\ 33^m\ 0^s
\end{array}
$$

In this case, 12^h must be added to the time shown by the chronometer, because the difference between the two values of the G. M. T. is about 12^h; this gives the Greenwich date corresponding to the ship's time as Oct. 22, $15^h\ 33^m$. Ans.

EXAMPLE 2.—At about $3^h\ 15^m$ A. M. on May 21, 1899, in longitude 77° 18′ W, the reading of the ship's chronometer was exactly $8^h\ 47^m\ 19^s$; the error of the instrument on Greenwich mean time is $7^m\ 21^s$ fast. Find the correct Greenwich mean time.

$$
\begin{array}{rl}
\text{SOLUTION.— Time at ship, May 21} = & 3^h\ 15^m \text{ A. M.} \\
\text{Or, Ast. time, May 20} = & 15^h\ 15^m\ 0^s \\
\text{Long. (W) in time} = & +\ 5^h\ 9^m\ 12^s \\
\hline
\text{Approx. G. D., May 20} = & 20^h\ 24^m\ 12^s \\
 & \\
\text{Chronometer} = & 8^h\ 47^m\ 19^s \\
\text{Error (fast)} = & -\ \ 7^m\ 21^s \\
\hline
 & 8^h\ 39^m\ 58^s \\
 & +\ 12^h\ 0^m\ 0^s \\
\hline
\text{G. M. T., or G. D., May 20} = & 20^h\ 39^m\ 58^s
\end{array}
$$

First find the astronomical time corresponding to May 21, $3^h\ 15^m$ A. M., by adding 12^h and putting the date back 1 da. It is also evident that 12^h must be added to the time indicated by the chronometer, which gives for the Greenwich date, May 20, $20^h\ 39^m\ 58^s$. Ans.

EXAMPLE 3.—On December 19, 1900, the local time at ship in longitude 125° 16′ W is $7^h\ 21^m\ 11^s$ A. M.; at the same time, the ship's chronometer, which is $4^m\ 11^s$ slow on Greenwich mean time, indicated $3^h\ 36^m\ 9^s$. Find the correct Greenwich date.

$$
\begin{array}{rl}
\text{SOLUTION.—Time at ship, Dec. 19} = & 7^h\ 21^m\ 11^s \text{ A. M.} \\
\text{Or, Ast. time, Dec. 18} = & 19^h\ 21^m\ 11^s \\
\text{Long. (W) in time} = & +\ 8^h\ 21^m\ 4^s \\
\hline
\text{Approx. G. D., Dec. 18} = & 27^h\ 42^m\ 15^s \\
\text{Or, Dec. 19} = & 3^h\ 42^m\ 15^s \\
 & \\
\text{Chronometer} = & 3^h\ 36^m\ 9^s \\
\text{Error (slow)} = & +\ \ 4^m\ 11^s \\
\hline
\text{G. M. T., or G. D., Dec. 19} = & 3^h\ 40^m\ 20^s. \text{ Ans.}
\end{array}
$$

It will be noticed in this case that the chronometer time agrees so nearly with the approximate Greenwich date found, that it is unnecessary to add 12^h as in the two preceding examples. Attention is also called to the fact that Dec. 18, $27^h\ 42^m\ 15^s$ means $27^h\ 42^m\ 15^s$ after the noon of Dec. 18, and is therefore written Dec. 19, $3^h\ 42^m\ 15^s$.

49. From the foregoing, it follows that, in order to obtain the time at any place corresponding to a given Greenwich time, the longitude of the place reduced to time must be subtracted from the Greenwich time if the longitude is west, but added if the longitude is east.

ILLUSTRATION.—Assume the time at Greenwich to be 9^h A. M.; what is the corresponding time at a place in longitude 45° W?

The longitude converted into time is 3 hr.; the place being to the west of Greenwich, its local time is accordingly 3 hr. earlier, and, hence, 3 hr. is subtracted from the time at Greenwich. Thus,

Local time = Greenwich time − Long. (W) in time
Local time = $9^h - 3^h = 6^h$ A. M. Ans.

If it is required to find the local time at a place in longitude 37° 30′ E, corresponding to 9^h A. M. at Greenwich, the longitude must then be converted into time and added. Thus, 37° 30′ = $2^h\ 30^m$.

Whence, local time = $9^h + 2^h\ 30^m = 11^h\ 30^m$ A. M. Ans.

EXAMPLES FOR PRACTICE

1. The sun is on the meridian at a place in longitude 96° W on June 15. What is the time at Greenwich? Ans. June 15, $6^h\ 24^m$

2. On April 18, in longitude 45° W, at about 7 A. M., local time, a chronometer indicated $9^h\ 47^m\ 45^s$, its error on Greenwich mean time being $13^m\ 15^s$ slow. Find the Greenwich date. Ans. Apr. 17, $22^h\ 1^m$

3. The local time of a ship in longitude 15° 45′ E, June 7, was $3^h\ 15^m$ A. M. Required, the corresponding Greenwich date.
Ans. June 6, $14^h\ 12^m$

4. Find the Greenwich date corresponding to $3^h\ 15^m$ P. M., local time, January 2, in longitude 117° E. Ans. Jan. 1, $19^h\ 27^m$

5. The local time of a ship, March 1, is $11^h\ 45^m$ P. M. At the same instant the chronometer indicated $7^h\ 10^m\ 30^s$, it being $9^m\ 5^s$ fast on Greenwich mean time. The longitude by account is 110° 35′ W. What is the corresponding Greenwich date? Ans. Mch. 1, $19^h\ 1^m\ 25^s$

6. The local time of a ship is $5^h\ 16^m$ P. M., November 27. The longitude is 90° 35′ E. Find the corresponding Greenwich date.
Ans. Nov. 26, $23^h\ 13^m\ 40^s$

HOW TO CORRECT ELEMENTS FOUND IN THE NAUTICAL ALMANAC

50. The Greenwich date at the instant of observation being found, the various elements taken from the Nautical Almanac must be corrected for the interval of time that has elapsed between the time of observation and the time for which they are given. Usually, the Greenwich date is expressed in *mean time*, but if the longitude in time has been applied to the local apparent time, the Greenwich date also will be expressed in *apparent time*.

The beginner should pay particular attention to the time with which he is dealing. He must remember that the chronometer indicates Greenwich mean time (G. M. T.), that the ship's clock, or his watch is supposed to show local mean time (L. M. T.), and that the sun always indicates local apparent time (L. App. T.). Hence, when the Greenwich date is expressed in mean time, he must take out from the Nautical Almanac the elements given for **mean time**; if expressed in apparent time, he must turn to those elements given for **apparent time.**

NOTE.—In the examples that follow, as well as in all calculations in this Course requiring the aid of a Nautical Almanac, the requisite elements should be taken from the abridgment of the Nautical Almanac for the year 1899 that accompanies this Section.

51. To Find the Sun's Declination.—The declination of the sun is tabulated in the Nautical Almanac for each day of the year at apparent and mean noon at Greenwich. When mean time is given, and it is required to find the sun's declination at any instant, proceed as follows:

Rule.—*Find the Greenwich date. From the Nautical Almanac, find the declination at mean noon nearest to the Greenwich date, also the corresponding change for 1 hour (Diff. for 1 hour) found in the adjoining column. Multiply this change by the hours (and fractions) contained between the Greenwich date and the noon for which the declination is taken out; the product will be the correction to be applied to the declination according as the declination is increasing or decreasing.*

EXAMPLE.—The Greenwich date, mean time, is January 3, 1899, $10^h\ 24^m$. Required, the sun's declination.

SOLUTION.—Proceed according to the foregoing rule. Thus,

Sun's Declination (Mean Noon)

Jan. 3 =	S 22° 49′ 19.5″	Change in 1^h =	14.79″ decrs.
Corr. for 10.4^h =	− 2′ 33.8″	Multiply by $10^h\ 24^m$, or ×	10.4^h
Decl. required =	S 22° 46′ 45.7″. Ans.		5916
			1479
		Corr. =	153.816″
		Or =	2′ 33.8″

Or, the declination may be taken out for the next noon, Jan. 4, and the change for 1 hr. multiplied by $24^h - 10.4^h = 13.6^h$. The correction will then have to be added; thus,

Sun's Declination (Mean Noon)

Jan. 4 =	S 22° 43′ 10.9″	Change in 1^h =	15.92″
Corr. for 13.6^h =	+ 3′ 36.5″		× 13.6^h
Decl. =	S 22° 46′ 47.4″. Ans.	Corr. =	216.512″
		Or =	3′ 36.5″

The slight discrepancy in the two results is due to the hourly change not being uniform. For the ordinary purpose of navigation, however, one decimal of the hourly change may be dropped; this will make the difference for 1 hr. both at mean and apparent noon about equal, and the inequality of change need not be taken into consideration.

52. The signs + and −, which are invariably found in the Nautical Almanac prefixed to the hourly change, sometimes confuse the beginner, who thinks that the correction for declination should be applied according to it. The application of the correction, however, depends on whether the declination is increasing or decreasing. In the preceding example, for instance, by comparing the declination for January 3 and 4, it will be seen that on the latter day the declination is less than on the previous one; hence, the declination is decreasing and must be less at the given Greenwich date than at the moment on January 3 for which it is given in the Nautical Almanac. For this reason, the correction is subtractive, although the hourly change is marked with the sign +. These signs mean that the celestial body is moving toward north or south; north if marked + and south if marked − . The sign + before the declination of a star or

planet means northerly declination, and the sign –, southerly declination. In all other cases, the signs + and – should be treated algebraically.

EXAMPLE.—Find the sun's declination on January 15, 1899, at 10^h A. M., local mean time in longitude 79° W.

SOLUTION.—	L. M. T., Jan. 15 =	$10^h\ 0^m$ A. M.
	Or, L. Ast. M. T., Jan. 14 =	$22^h\ 0^m$
	Long. (W) in time =	$+\ 5^h\ 16^m$
	G. D., Jan. 15 =	$3^h\ 16^m$

Sun's Declination (Mean Noon)

Jan. 15 =	S. 21° 6′ 38″	Change in 1^h =	27.7″ decrs.
Corr. for $3^h\ 16^m$ =	– 1′ 31.4″	Multiply by $3^h\ 16^m$, or ×	3.3^h
Decl. required =	S. 21° 5′ 6.6″. Ans.		831
			831
		Cor. =	91.41″
		Or =	1′31.4″

The correction in this case is subtracted from the noon declination, as the declination is decreasing.

53. For all practical purposes, in correcting elements taken from the Nautical Almanac, the method of finding the Greenwich date as given in Art. **47** is sufficiently accurate. However, if the observer is desirous of using the correct Greenwich mean time, the reading of the chronometer at the instant of observation should be noted and the Greenwich date found according to Art. **48.**

EXAMPLE.—Find the sun's declination on June 19, 1899, at 11 A. M., local mean time in longitude 33° E.

SOLUTION.—	L. M. T., June 19 =	$11^h\ 0^m$ A. M.
	Or, L. Ast. M. T., June 18 =	$23^h\ 0^m$
	Long. (E) in time =	$–\ 2^h\ 12^m$
	G. D., June 18 =	$20^h\ 48^m$

Sun's Declination (Mean Noon)

June 19 =	N 23° 26′ 9.5″	Change in 1^h =	2.2″ incrs.
Corr. for $3^h\ 12^m$ =	– 7″	Multiply by $3^h\ 12^m$, or ×	3.2^h
Decl. required =	N 23° 26′ 2.5″. Ans.		44
			66
		Corr. =	7.04″

In this example it will be noticed that the Greenwich date is more than 20^h; hence, the declination is taken out for noon of June 19 and the hourly change multiplied by $24^h - 20^h\ 48^m = 3^h\ 12^m$. Also, since the declination at noon of June 19 is greater than at noon of June 18, it follows that the declination at the required moment is less than at noon of June 19. Hence, the correction is to be subtracted.

54. Whenever the Greenwich date is more than 12 hours, the declination (and other elements of the sun) should be taken out for the following noon and the correction applied accordingly. The same rule applies to the equation of time whenever that quantity is required.

Example.—The local apparent time of a ship March 15, 1899, is $5^h\ 40^m$ P. M. The longitude is 40° 45′ W. Find the sun's declination.

Solution.— L. App. T., Mch. 15 = $5^h\ 40^m$ P. M.
Long. (W) in time = $+\ 2^h\ 43^m$

G. D., App. time, Mch. 15 = $8^h\ 23^m$

Sun's Declination (App. Noon)

Mch. 15 = S 2° 6′ 3.3″ Change in 1^h = 59.2″ decrs.
Corr. for $8^h\ 23^m$ = − 8′ 17.3″ Multiply by $8^h\ 23^m$, or $\times\ 8.4^h$

Decl. required = S 1° 57′ 46″. Ans.

$$\begin{array}{r} 2368 \\ 4736 \\ \hline \text{Corr.} = 497.28'' \\ \text{Or} = 8'\ 17.3'' \end{array}$$

In this case, by applying the longitude in time to the local apparent time, the Greenwich date is expressed in apparent time. Hence, the declination should be taken out for apparent noon and corrected as usual for the difference in time.

55. To Find the Equation of Time.—The equation of time is tabulated in the Nautical Almanac for each day of the year, for both mean and apparent noon at Greenwich. To obtain its value at any given time, proceed as follows:

Rule.—*Find the Greenwich date. From the Nautical Almanac, find the equation of time for the nearest Greenwich mean noon and the corresponding hourly change (Diff. for 1 hour). Multiply this hourly change by the number of hours (and fraction) contained between the Greenwich date and the noon for which the equation of time is taken out. The result will be the correction to be applied according as the equation of time is increasing or decreasing.*

EXAMPLE 1.—The local mean time of a ship in longitude 16° 30′ E, January 1, 1899, was $9^h\ 26^m$ A. M. Find the equation of time at that instant.

SOLUTION.—L. M. T., Jan. 1, 1899, is $9^h\ 26^m$ A. M., which is equal to

$$\begin{aligned} \text{L. Ast. M. T., Dec. 31, 1898} &= 21^h\ 26^m \\ \text{Long. (E) in time} &= -\ \ 1^h\ \ 6^m \\ \hline \text{G. D., Dec. 31, 1898} &= 20^h\ 20^m \end{aligned}$$

Equation of Time (Mean Noon)

$$\begin{array}{rll} \text{Jan. 1, 1899} = & 3^m\ 47.24^s & \text{Change in } 1^h = 1.2^s \text{ incrs.} \\ \text{Corr. for } 3^h\ 40^m = & -\quad 4.44^s & \text{Multiply by } 3^h\ 40^m\text{, or } \times 3.7^h \\ \hline \text{Eq. of T. required} = & 3^m\ 42.8^s. \quad \text{Ans.} & \phantom{\text{Corr.} = } 84 \\ & & \phantom{\text{Corr.} = } 36 \\ \hline & & \text{Corr.} = 4.44^s \end{array}$$

The Greenwich date Dec. 31, 1898, being greater than 12^h, the equation of time is taken out for noon of the following day, Jan. 1, 1899, and the correction applied accordingly.

EXAMPLE 2.—The mean time of a ship on March 2, 1899, is $6^h\ 10^m$ P. M. The longitude is 39° W. Required, the equation of time.

SOLUTION.—

$$\begin{aligned} \text{L. M. T., Mch. 2} &= 6^h\ 10^m \text{ P. M.} \\ \text{Long. (W) in time} &= +\ 2^h\ 36^m \\ \hline \text{G. D., Mch. 2} &= 8^h\ 46^m \end{aligned}$$

Equation of Time (Mean Noon)

$$\begin{array}{rll} \text{Mch. 2} = & 12^m\ 19.48^s & \text{Change in } 1^h = 0.5^s \text{ decrs.} \\ \text{Corr. for } 8^h\ 46^m = & -\qquad 4.4^s & \text{Multiply by } 8^h\ 46^m\text{, or } \times 8.8^h \\ \hline \text{Eq. of T. required} = & 12^m\ 15.08^s. \quad \text{Ans.} & \text{Corr.} = 4.4^s \end{array}$$

When taking out the equation of time, it should be noticed whether it is additive to or subtractive from the mean or apparent time. The arrangement at the head of the column containing the equation of time will minimize the possibility of any error being committed in this respect.

56. To Find the Sun's Semi-Diameter.—As previously stated, the sun's semi-diameter is taken directly from the Nautical Almanac; no correction is needed because of its slow change. The semi-diameter is given for mean noon of each day, but may be considered as correct for any hour of the day.

57. To Find the Right Ascension of the Mean Sun. The right ascension of the mean sun (usually denoted by

R. A. M. S.) at Greenwich mean noon, which is the same as the sidereal time of mean noon, is recorded in the Nautical Almanac for each day of the year. It is found in the last column on the page marked II of each month, under the heading Sidereal Time. The motion of the mean sun is *uniform;* hence, its hourly change ($= 9.8565^s$) is constant, and the correction for any number of hours can therefore be readily found at any time by a simple multiplication, or more conveniently by Table III at the end of the Nautical Almanac. Furthermore, since the right ascension is continually increasing, the correction taken from this table is always *additive* to the sidereal time.

Rule.—*Find the Greenwich date. Take from the Nautical Almanac the sidereal time at Greenwich mean noon for the given date and add it to the correction (Table III, Nautical Almanac) corresponding to the hours, etc. of the Greenwich date. The sum will be the required right ascension of the mean sun.*

EXAMPLE 1.—In longitude 49° W, June 15, 1899, the local mean time is $6^h\ 15^m$ P. M. Required, the right ascension of the mean sun at that moment.

SOLUTION.—Proceed according to the foregoing rule. Thus,

$$
\begin{array}{rl}
\text{L. M. T., June 15} = & 6^h\ 15^m \\
\text{Long. (W) in time} = & \underline{+3^h\ 16^m} \\
\text{G. D., June 15} = & 9^h\ 31^m \\
\text{Sid. time G. M. N., June 15} = & 5^h\ 34^m\ 12.35^s \\
\text{Table III, Corr. for } 9^h\ 31^m = & \underline{1^m\ 33.8^s} \\
\text{Required R. A. M. S.} = & 5^h\ 35^m\ 46.15^s. \quad \text{Ans.}
\end{array}
$$

EXAMPLE 2.—On January 6, 1899, in longitude 114° 45′ E, the local mean time is $6^h\ 18^m$ A. M. Required, the right ascension of the mean sun.

SOLUTION.—

$$
\begin{array}{rl}
\text{L. M. T., Jan. 6} = & 6^h\ 18^m \text{ A. M.} \\
\text{Or, L. Ast. M. T., Jan. 5} = & 18^h\ 18^m \\
\text{Long. (E) in time} = & \underline{-\ 7^h\ 39^m} \\
\text{G. D., Jan. 5} = & 10^h\ 39^m \\
\text{Sid. time G. M. N., Jan. 5} = & 18^h\ 59^m\ 26.97^s \\
\text{Table III, Corr. for } 10^h\ 39^m = & \underline{1^m\ 45^s} \\
\text{Required R. A. M. S.} = & 19^h\ \ 1^m\ 11.97^s. \quad \text{Ans.}
\end{array}
$$

The right ascension of the mean sun is also equal to the right ascension of the true sun plus the equation of time,

using the sign for the equation of time indicated for its application to mean time.

58. To Find the Moon's Declination and Right Ascension.—The moon's declination and right ascension are recorded for each hour of the day, and the change in 1 minute of time at the commencement of each hour is also given. In the regular Nautical Almanacs, these elements will be found on pages marked V to XII of each month.

Rule.—*Find the Greenwich date. From the Nautical Almanac, find the moon's right ascension and declination for the given hour; also their respective changes for 1 minute. Multiply the change of each by the number of minutes (and fractions) of the Greenwich date. The product of the former will be the correction to be* **added** *to the right ascension, while the product of the latter will be the correction to be applied to the declination, according as that quantity is increasing or decreasing.*

NOTE.—Abstracts of the moon's declination and right ascension for the dates given in the examples are found on the fourth or fifth page of each month in the Nautical Almanac accompanying this Section.

EXAMPLE 1.—The local mean time of a ship October 16, 1899, is $2^h\ 19^m\ 18^s$ A. M. Longitude = 109° 30′ W. Find the moon's right ascension and declination at that instant.

SOLUTION.—

L. M. T., Oct. 16	=	$2^h\ 19^m\ 18^s$ A. M.
Or, L. Ast. M. T., Oct. 15	=	$14^h\ 19^m\ 18^s$
Long. (W) in time	=	$+\ 7^h\ 18^m\ 0^s$
G. D., Oct. 15	=	$21^h\ 37^m\ 18^s$

☽ Decl.	= S 0° 4′ 16.1″	Change in 1^m	= 14.511″
Corr. for 37.3^m	= 9′ 1.26″		$\times\ 37.3^m$
☽ Decl. required	= N 0° 4′ 45.2″. Ans.		43533
			101577
			43533
			60)541.2603″
		Corr.	= 9′ 1.26″

☽ R. A.	= $23^h\ 8^m\ 7.17^s$	Change in 1^m	= 2.248^s
Corr. for 37.3^m	= $+\ 1^m\ 23.85^s$		$\times 37.3^m$
☽ R. A. required	= $23^h\ 9^m\ 31^s$. Ans.		6744
			15736
			6744
			$60)83.8504^s$
		Corr.	= $1^m\ 23.85^s$

A glance at the Nautical Almanac will reveal the fact that between the hours of 21 and 22, Oct. 15, the moon's declination is changing from south to north. Hence, the correction being greater than the declination at 21^h, the latter should be subtracted from the former; the result, $0° 4' 45.2''$, will be the required declination, but is named north instead of south.

EXAMPLE 2.—The local mean time June 24, 1899, is $5^h 43^m 45^s$ A. M. Longitude = $64° 15'$ W. Find the moon's right ascension.

SOLUTION.—

$$\begin{aligned} \text{L. M. T., June 24} &= 5^h\ 43^m\ 45^s \text{ A. M.} \\ \text{Or, L. Ast. M. T., June 23} &= 17^h\ 43^m\ 45^s \\ \text{Long. (W) in time} &= +\ 4^h\ 17^m\ 0^s \\ \hline \text{G. D., June 23} &= 22^h\ 0^m\ 45^s \end{aligned}$$

$$\begin{aligned} ☽\ \text{R. A.} &= 19^h\ 0^m\ 11.54^s \\ \text{Corr. for } 0.75^m &= +1.97^s \\ \hline ☽\ \text{R. A. required} &= 19^h\ 0^m\ 13.5^s. \text{ Ans.} \end{aligned}$$

$$\begin{aligned} \text{Change in } 1^m &= 2.624^s \\ &\times 0.75^m \\ \hline &13120 \\ &18368 \\ \hline \text{Corr.} &= 1.96800^s \end{aligned}$$

EXAMPLE 3.—The local mean time December 23, 1899, is $9^h 43^m$ P.M. Longitude = $72° 45'$ E. What is the moon's declination at that time?

SOLUTION.—

$$\begin{aligned} \text{L. M. T., Dec. 23} &= 9^h\ 43^m \text{ P.M.} \\ \text{Long. (E) in time} &= -\ 4^h\ 51^m \\ \hline \text{G. D., Dec. 23} &= 4^h\ 52^m \end{aligned}$$

$$\begin{aligned} ☽\ \text{Decl.} &= \text{N } 0°\ 56'\ 32.2'' \\ \text{Corr. for } 52^m &= -10'\ 2.7'' \\ \hline ☽\ \text{Decl. required} &= \text{N } 0°\ 46'\ 29.5''. \text{ Ans.} \end{aligned}$$

$$\begin{aligned} \text{Change in } 1^m &= 11.59'' \\ &\times 52^m \\ \hline &2318 \\ &5795 \\ \hline &60)\ 602.68'' \\ \text{Corr.} &= 10'\ 2.7'' \end{aligned}$$

Since the declination is decreasing, the correction for the minutes of time must be subtracted.

NOTE.—Attention is called to the fact that in the English Nautical Almanac the change of the moon's right ascension and declination is given for 10 minutes of time, while in the American Nautical Almanac it is given for 1 minute. Therefore, when taking any of these elements from the former, the decimal point in the "variation for 10 minutes" should be moved one place to the left, either before or after the multiplication.

59. To Find the Moon's Semi-Diameter and Horizontal Parallax.—The moon's semi-diameter and horizontal parallax are tabulated in the Nautical Almanac for noon and midnight (mean time) of each day.

Rule.—*Find the Greenwich date. From the Nautical Almanac find the moon's semi-diameter for the epochs between which the hours of the Greenwich date lie, take their difference and divide by 12. The result multiplied by the hours (and fraction) of the Greenwich date is the correction to be applied, according to its sign, to the semi-diameter at the earlier epoch.*

For the horizontal parallax, take out that quantity for the time nearest the Greenwich date; also the change for 1 hour. Multiply this hourly change by the hours (and fraction) of the Greenwich date, and apply to the parallax according to its sign.

EXAMPLE 1.—The local mean time August 16, 1899, is $5^h\ 20^m$ A. M. Longitude = 116° E. Find the moon's semi-diameter and horizontal parallax.

SOLUTION.—

L. M. T., Aug. 16 =	$5^h\ 20^m$ A. M.
Or, L. Ast. M. T., Aug. 15 =	$17^h\ 20^m$
Long. (E) in time =	$-\ 7^h\ 44^m$
G. D., Aug. 15 =	$9^h\ 36^m$

☽ S. D., noon, Aug. 15 =	15′ 48.3″
☽ S. D., midnight, Aug. 15 =	15′ 55.9″
Change in 12^h =	7.6″
Change for 1^h = 7.6″ ÷ 12 =	0.63″
Multiply by hours of G. D. =	$\times\ 9.6^h$
Corr. =	6.05″

☽ S. D., noon, Aug. 15 =	15′ 48.3″
Corr. for 9.6^h =	+ 6.05″
☽ S. D. required =	15′ 54.35″. Ans.

☽ H. P., noon, Aug. 15 =	57′ 53.8″	Change in 1^h =	2.28″
Corr. for 9.6^h =	+ 21.9″		$\times\ 9.6^h$
☽ H. P. required =	58′ 15.7″. Ans.		1368
			2052
		Corr. =	21.888″

In this case, both the semi-diameter and the horizontal parallax are increasing; hence, the corrections for the hours of Greenwich date are additive. When the horizontal parallax of the moon is required with great accuracy and the Greenwich date is nearer midnight than noon, as in the example just given, it is better to use the hourly difference given at midnight and multiply it by the hours and fractions in the interval from the Greenwich date to midnight. In the present case, for instance,

the correction applicable to the value given at midnight would be $(12^h - 9.6^h =) 2.4^h \times 2.31'' = 5.5''$, the resulting parallax being 58′ 16″.

The semi-diameter thus found is the horizontal semi-diameter and should be corrected for augmentation, according to instructions given in *Nautical Astronomy*, Part 1.

The horizontal parallax found in the Nautical Almanac is the equatorial horizontal parallax, which is greatest at the equator and decreases as the latitude increases. Hence, in cases where great accuracy is required, a correction for latitude should be applied. This correction (which is negative) is found on page 167 of the Nautical Tables.

To obtain the parallax in altitude of the moon from its horizontal parallax, use the formula given in *Nautical Astronomy*, Part 1.

EXAMPLE 2.—The local mean time of a ship in latitude 48° N and longitude 169° W, September 12, 1899, is $11^h\ 32^m$ P. M. The apparent altitude of the moon is 64°. Required, the moon's horizontal parallax and semi-diameter, considering the altitude and latitude.

SOLUTION.— L. M. T., Sept. 12 = $11^h\ 32^m$ P. M.
Long. (W) in time = + $11^h\ 16^m$

G. D., Sept. 12 = $22^h\ 48^m$

☽ S. D., midnight, Sept. 12 = 15′ 51.9″
☽ S. D., noon, Sept. 13 = 15′ 58.3″

Diff. in 12^h = 6.4″
Change for $1^h = 6.4'' \div 12$ = 0.53″
$(22^h\ 48^m - 12^h)$ = × 10.8^h

Corr. = 5.724″

☽ S. D., midnight, Sept. 12 = 15′ 51.9″
Corr. for 10.8^h = + 5.7″

Hor. S. D. = 15′ 57.6″
Augmentation for App. Alt. (N. T., page 167) = + 15.0″

☽ S. D. required = 16′ 12.6″. Ans.

☽ H. P., midnight, Sept. 12 = 58′ 6.9″ Change in 1^h = 1.94″
Corr. for 10.8^h = + 20.9″ × 10.8^h

Corr. equatorial H. P. = 58′ 27.8″ Corr. = 20.952″
Reduction for Lat. (N. T., page 167) = − 6.2″

☽ H. P. required = 58′ 21.6″. Ans.

For all practical purposes, the correction for latitude may be omitted (its value never exceeding 12″), and the corrected equatorial horizontal parallax may be considered as the value at the place of observation.

60. To Find a Planet's Declination and Right Ascension.—The declination and the right ascension of planets are tabulated in the Nautical Almanac at Greenwich mean noon for each day of the year together with the corresponding change for 1 hour.

The Greenwich date being found, the required quantities are taken out with their hourly change, which, multiplied by the hours (and fractions) of the Greenwich date, will give the corrections to be applied to the values given for mean noon according to their signs.

EXAMPLE.—The local mean time April 10, 1899, is $8^h\ 24^m$ P. M. Longitude = 94° 30′ W. Find the right ascension and the declination of the planet Mars at that instant.

SOLUTION.—

$$\begin{array}{rl} \text{L. M. T., Apr. 10} = & 8^h\ 24^m \text{ P. M.} \\ \text{Long. (W) in time} = & +\ 6^h\ 18^m \\ \hline \text{G. D., Apr. 10} = & 14^h\ 42^m \end{array}$$

$$\begin{array}{rlrl} \text{Planet Mars's R. A., Apr. 10} = & 8^h\ 3^m\ 10.59^s & \text{Change in } 1^h = & 3.786^s \\ \text{Corr. for } 14.7^h = & +\quad 55.65^s & & \times\ 14.7^h \\ \hline \text{R. A. required} = & 8^h\ 4^m\ 6.24^s. \text{ Ans.} & \text{Corr.} = & 55.6542^s \end{array}$$

$$\begin{array}{rlrl} \text{Planet Mars's Decl., Apr. 10} = & \text{N } 22°\ 57'\ 24.3'' & \text{Change in } 1^h = & 14.68'' \\ \text{Corr. for } 14.7^h = & -\quad 3'\ 35.8'' & & \times\ 14.7^h \\ \hline \text{Decl. required} = & \text{N } 22°\ 53'\ 48.5''. \text{ Ans.} & & 215.796'' \\ & & \text{Corr.} = & 3'\ 35.8'' \end{array}$$

61. The semi-diameters and horizontal parallaxes of the different planets used for observations at sea are found in the Nautical Almanac at the bottom of each page devoted to the element of planets. These quantities do not require to be corrected for the hours of the Greenwich date, because their daily change is very slight.

62. To Find the Right Ascension and Declination of a Fixed Star.—The right ascension and the declination of stars are tabulated in the Nautical Almanac under the

heading Fixed Stars for the beginning of each year, as is also the annual variation of each quantity.

To find any of these quantities for a certain star at a certain date, take out of the Nautical Almanac its value and corresponding annual variation, or change, in 12 months. Divide this change by 12, and multiply by the number of months (and fractions) of the given date. The result will be the correction to be applied to the value previously taken out, according to the sign prefixed to the annual variation.

EXAMPLE.—Find the right ascension and the declination of the star Sirius (α Canis Majoris) on April 15, 1899.

SOLUTION.—

$$
\begin{array}{rl}
\text{R. A. Sirius} = & 6^h\,40^m\,41.85^s \\
\text{Corr. for 3.5 months} = & +\qquad 0.77^s \\
\hline
\text{R. A. required} = & 6^h\,40^m\,42.6^s. \text{ Ans.}
\end{array}
\qquad
\begin{array}{l}
\text{Annual Var.} = +\,2.64^s \\
\text{Corr.} = \dfrac{2.64}{12} \times 3.5 = 0.77^s
\end{array}
$$

$$
\begin{array}{rl}
\text{Decl. Sirius} = & -\,16°\,34'\,39.3'' \\
\text{Corr. for 3.5 months} = & -\qquad 1.4'' \\
\hline
\text{Decl. required} = & \text{S } 16°\,34'\,40.7''. \text{ Ans.}
\end{array}
\qquad
\begin{array}{l}
\text{Annual Var.} = -\,4.7'' \\
\text{Corr.} = \dfrac{4.7}{12} \times 3.5 = 1.4''
\end{array}
$$

Both the declination and the correction having the same sign, their sum will give the required value at the given time. Since this correction is very small, it may be omitted in practice, and both quantities taken directly from the Nautical Almanac.

63. To Find the Local Time of the Moon's Meridian Passage in Any Longitude.—The time of the moon's meridian passage (upper culmination, or transit) at Greenwich is tabulated for each day in the Nautical Almanac. This time is the same as the hour angle of the mean sun at the instant the moon passes the meridian at Greenwich, or the difference between the right ascension of the moon and the mean sun. If this difference did not change, the local mean time of the moon's meridian passage would be the same for all meridians. But the moon's right ascension increases more rapidly than that of the sun on account of the former's more rapid motion in its orbit, and, therefore, the moon's meridian passage is belated each day by an interval of time varying from 40^m to 66^m, the exact amount depending on the number of minutes by which the increase of the right

ascension of the moon exceeds that of the mean sun. Now, since the earth rotates from west to east, and the moon is constantly changing its angular distance eastward from the sun, it is evident that this interval is less when the moon crosses the meridian of a place in east longitude and greater for a place in west longitude. In other words, the moon is farther to the east each day with regard to the meridians, which revolve from west to east with the earth. For instance, if the moon on a certain day crosses the observer's meridian at the same instant as the mean sun, it will, on the next day, cross the same meridian 49^m later than the mean sun (assuming the mean value of the interval to be 49^m). Hence, at a place in longitude 90° W, the meridian passage of the moon will take place at $6^h + \frac{90°}{360°} \times 49^m = 6^h\ 12^m$ later than the passage at the meridian of Greenwich; and at a place in longitude 90° E, it will occur $6^h - \frac{90°}{360°} \times 49^m = 5^h\ 48^m$, or $6^h\ 12^m$ earlier than the meridian passage at Greenwich. The difference between two successive meridian passages given in the Nautical Almanac is the *retardation* of the moon in passing over 360°, or 24^h, of longitude, and the hourly difference given is the retardation in passing from the Greenwich meridian to the meridian 15°, or 1^h, from Greenwich. From the foregoing is obtained the following rule to find the local time of the moon's meridian passage:

Rule—I. *Find from the Nautical Almanac the mean time of the moon's meridian passage for the given civil date. Apply to it a correction equal to the hourly difference multiplied by the longitude in time, adding this correction when the longitude is west, but subtracting it when the longitude is east.*

II. *If, by inspection, it is found that the time of transit when corrected for longitude exceeds 12 hours, take it out for the preceding day; if not over 12 hours, for the given date. The result will be the local mean time of local transit.*

EXAMPLE 1.—On February 14, 1899, in longitude 78° 15′ W, an observer intending to measure the meridian altitude of the moon, for

the purpose of determining his latitude, desired to find the time of the moon's meridian passage. What time did the moon cross the meridian?

SOLUTION.—

☽ Mer. passage, Feb. 14	= $3^h\ 40.8^m$	Diff. in 1^h	=	2.08^m
Corr. for Long. (W) in time 5.2^h	= $+\ 10.8^m$	Long. in time	=	$\times\ 5.2^h$
L. M. T. of passage, Feb. 14	= $3^h\ 51.6^m$	Corr.	=	10.816^m

Hence, the moon crossed the meridian at 3.51 P. M., local mean time. Ans.

EXAMPLE 2.—Find the time of the moon's transit on May 5, 1899, in longitude 96° 25′ W.

SOLUTION.—

☽ Mer. passage, May 4	= $20^h\ 19.3^m$	Diff. in 1^h	=	2.03^m
Corr. for Long. (W) in time 6.4^h	= $+\ 13.0$	Long. in time	=	$\times\ 6.4^h$
L. M. T. of passage, May 4	= $20^h\ 32.3^m$	Corr.	=	12.992^m
Or, May 5	= $8^h\ 32.3^m$ A. M.			

In this case, the time of transit is taken out for the date preceding, or for May 4, because the time recorded in the Nautical Almanac for May 5 greatly exceeds 12 hr. Ans.

If it is desired to know the Greenwich time corresponding to the local time of transit, the longitude is applied according to the rule of Art. 47.

EXAMPLE 3.—Find the time of the moon's meridian passage March 12, 1899, in longitude 100° 30′ E; also the corresponding mean time at Greenwich.

SOLUTION.—

☽ Mer. passage, Mch. 12	= $0^h\ 36.8^m$	Diff. in 1^h	=	2.12^m
Corr. for Long. (E) in time 6.7^h	= $-\ \ 14.2$	Long. in time	=	$\times\ 6.7^h$
L. M. T. of passage, Mch. 12	= $0^h\ 22.6^m$. Ans.	Corr.	=	14.204^m
Long. (E) in time	= $-\ 6^h\ 42^m$			
G. M. T., Mch. 11	= $17^h\ 40.6^m$. Ans.			

EXAMPLE 4.—Find the time of the meridian passage of the moon on August 4, in longitude 169° 30′ W; also, the corresponding mean time at Greenwich.

SOLUTION.—

☽ Mer. passage, Aug. 3	= $22^h\ 32^m$	Diff. in 1^h	=	1.96^m
Corr. for Long. (W) in time 11.3^h	= $+\ \ 22^m$			$\times\ 11.3^h$
L. M. T. of passage, Aug. 3	= $22^h\ 54^m$. Ans.	Corr.	=	22.148^m
Long. (W) in time	= $+\ 11^h\ 18^m$			
G. M. T., Aug. 4	= $10^h\ 12^m$. Ans.			

Hence, the moon will cross the meridian in longitude 169° 30′ W, Aug. 3, at $22^h\ 54^m$, local mean time, or Aug. 4, $10^h\ 54^m$ A. M., civil time.

NOTE.—To find the local mean time of the moon's meridian passage from almanacs where no "Diff. for 1 hour" is given, take out the time of the moon's meridian passage for the given day and the day *before* for east longitude; or, for the given day and the day *after* for west longitude. The difference in either case, multiplied by $\frac{\text{longitude}}{360°}$ will be the correction to be applied to the time for the given day, subtracting it if the longitude is east, but adding it if the longitude is west.

64. To Find the Time of a Planet's Meridian Passage in Any Longitude.—The method of finding the meridian passage of a planet is the same as in the case of the moon, except that the time of passage on any day is not always later than that on the preceding day. The cause of this is that, on account of the apparent motion of the planets, their right ascensions sometimes increase and sometimes decrease, while the right ascension of the mean sun is constantly increasing. Hence, when the right ascension of a planet increases more rapidly than that of the mean sun, the time of its meridian passage will occur later day by day. When the rate of increase is equal to that of the mean sun, the time of passage will be practically the same on successive days; and when it is less, or when the right ascension of the planet is decreasing, the time of passage will occur earlier day by day. Therefore, the correction is sometimes applied in an opposite way to that given in the examples relating to the moon. These changes are, however, easily traced, by inspection, in the Nautical Almanac. Thus, when the transit is belated from one day to the next, the procedure is exactly the same as for finding the transit of the moon; when earlier from day to day, the sign of the correction for longitude is reversed.

EXAMPLE.—At what time will the planet Mars pass the meridian of a place in longitude 60° E, January 19, 1899?

SOLUTION.—Applying the principles of the rule given in the note, Art. **63**, the solution is effected as follows:

According to the Nautical Almanac,

$$\begin{aligned} \text{Mars's Mer. passage, Jan. 19} &= 12^h\ 9.0^m \\ \text{Mars's Mer. passage, Jan. 18} &= 12^h\ 14.6^m \\ \hline \text{Diff.} &= 0^h\ 5.6^m \end{aligned}$$

$$\begin{array}{rl} \text{Mars's Mer. passage, Jan. } 19 = & 12^h\ 9^m \\ \text{Corr.} = \frac{60}{360} \times 5.6 = & +\ \ 0.9^m \\ \hline \text{L. M. T. of passage, Jan. } 19 = & 12^h\ 9.9^m. \quad \text{Ans.} \end{array}$$

Since in this case the transit of Mars occurs earlier each day (see Nautical Almanac) and the longitude is east, the correction is additive.

As the greatest daily variation in the meridian passage of the planets amounts to only 6 minutes, the time of transit for any planet may, for all practical purposes of navigation, be taken directly without any correction from the Nautical Almanac.

The main purpose of finding the time of transit of a planet (or a star) at sea is to be on hand at culmination to measure the meridian altitude; and, since the planet at that time will remain stationary for several minutes, it is evident that strict accuracy in determining the time of transit is unnecessary.

EXAMPLES FOR PRACTICE

1. The local mean time at a ship in longitude 115° 56′ E, June 15, 1899, is $7^h\ 30^m$ A. M. Find the Greenwich date.

Ans. G. D. June 14, $11^h\ 46^m\ 16^s$

2. The local mean time at a ship in longitude 171° W, September 22, 1899, is $10^h\ 30^m$ P. M. Required, the sun's declination for that instant.

Ans. Decl. = S 0° 3′ 18.8″

3. It is apparent noon at a ship in longitude 50° W, March 2, 1899. Find the sun's declination.

Ans. Decl. = S 7° 6′ 57.8″

4. The local mean time October 22, 1899, is $12^h\ 0^m\ 45^s$ P. M. Longitude = 35° E. Required, the right ascension of the mean sun.

Ans. R. A. M. S. = $14^h\ 4^m\ 23.3^s$

5. The mean time at a ship in longitude 59° 30′ W is $4^h\ 51^m\ 16^s$ P. M., March 25, 1899. Find the moon's right ascension and declination at that instant.

$$\text{Ans.} \begin{cases} \text{R. A.} = 11^h\ 11^m\ 19.9^s \\ \text{Decl.} = \text{S } 0°\ 1'\ 3'' \end{cases}$$

6. Find: (*a*) the equation of time for the same instant as given in the previous example, and (*b*) state whether it is additive to, or subtractive from, mean time.

$$\text{Ans.} \begin{cases} (a)\ \text{Eq. of T.} = 5^m\ 59.2^s \\ (b)\ \text{Subtractive} \end{cases}$$

7. Find the local mean time of the moon's meridian passage in longitude 125° 25′ E, June 28, 1899.

Ans. Mean time of passage June 28 at $3^h\ 55.5^m$ A. M.

8. The local mean time June 15, 1899, is $8^h\ 18^m\ 49^s$ P. M. Longitude = 78° W. Find the moon's right ascension and declination.

Ans. $\begin{cases} \text{R. A.} = 11^h\ 17^m\ 58.7^s \\ \text{Decl.} = \text{S } 1°\ 9'\ 41.3'' \end{cases}$

9. What is the local mean time of the moon's meridian passage on December 22, 1899, in longitude 76° 30′ E?

Ans. Mean time of passage Dec. 22 at $3^h\ 40.9^m$ A. M.

10. If an observer is in longitude 94° 45′ W, (*a*) at what time will the moon be in transit on his meridian on July 19, 1899? (*b*) What is the corresponding Greenwich time?

Ans. $\begin{cases} \text{Local time of passage July 19 at } 9^h\ 20.9^m \\ \text{Greenwich time of passage July 20 at } 3^h\ 39.9^m \text{ A. M.} \end{cases}$

11. On September 25, 1899, at $8^h\ 4^m\ 30^s$, local mean time, in latitude 80° N and longitude 116° W, the moon's apparent altitude was 52°. Find the moon's semi-diameter and horizontal parallax.

Ans. $\begin{cases} \text{S. D.} = 15'\ 21.1'' \\ \text{H. P.} = 55'\ 20.7'' \end{cases}$

12. Find the right ascension and the declination of the planet Jupiter on January 6, 1899, when the mean time at ship is $9^h\ 43^m\ 40^s$ P.M., the ship's longitude being 58° 30′ W.

Ans. $\begin{cases} \text{R. A.} = 14^h\ 19^m\ 34^s \\ \text{Decl.} = \text{S } 12°\ 40'\ 39'' \end{cases}$

13. Find the local mean time of the moon's meridian passage at a place in longitude 179° 20′ E, September 19, 1899.

Ans. Mean time of passage Sept. 19, at $11^h\ 44.4^m$ P. M.

14. Find the local mean time when the planet Jupiter will be on the meridian of a place in longitude 37° W, January 14, 1899; also, the corresponding Greenwich mean time.

Ans. $\begin{cases} \text{L. M. T. of passage Jan. 13, } 15^h\ 4.5^m\text{, or Jan. 14, } 3^h\ 4.5^m \text{ A. M.} \\ \text{Corres. G. M. T. Jan. 13} = 17^h\ 32.5^m\text{, or Jan. 14, } 5^h\ 32.5^m \text{ A. M.} \end{cases}$

PROBLEMS RELATING TO TIME

65. To Convert Mean Into Apparent Time, and Apparent Into Mean Time.—Since the equation of time is the difference between the time measured by the mean sun and that measured by the true sun, it is evident that by applying to either time, the equation of time, properly corrected, the corresponding mean or apparent time is found. Hence, the following rule:

Rule.—*Find the Greenwich date. Correct the equation of time according to Art.* 55 *and apply it to the given time as directed in the Nautical Almanac. The result is the time required.*

Example 1.—The local mean time of a ship in longitude 16° W, April 27, 1899, is $9^h\ 10^m$ P. M. Find the corresponding apparent time.

Solution.— L. M. T., Apr. 27 = $9^h\ 10^m$ P. M.
Long. (W) in time = $1^h\ 4^m$
G. D., Apr. 27 = $10^h\ 14^m$

Equation of Time (Mean Noon)

Apr. 27 = $2^m\ 25.16^s$ Change in 1^h = 0.4^s incrs.
Corr. for 10.2^h = + 4.08^s $\times\ 10.2^h$
Corr. Eq. of T. = $2^m\ 29.24^s$(+) Corr. = 4.08^s
L. M. T., Apr. 27 = $9^h\ 10^m\ 0^s$
App. time required = $9^h\ 12^m\ 29.24^s$. Ans.

According to the Nautical Almanac, the equation of time in this case is additive to local mean time; therefore, the sign (+) is placed to the right of the corrected equation of time, as shown in the solution.

Example 2.—The local apparent time of a ship in longitude 16° 30′ E, January 1, 1899, is $9^h\ 26^m$ A. M. Required, the corresponding mean time.

Solution.— L. App. T., Dec. 31 = $21^h\ 26^m$
Long. (E) in time = − $1^h\ 6^m$
G. D., Dec. 31 = $20^h\ 20^m$

Equation of Time (App. Noon)

Jan. 1 = $3^m\ 47.32^s$ Change in 1^h = 1.17^s
Corr. for 3.7^h = − 4.33^s $\times\ 3.7^h$
Corr. Eq. of T. = $3^m\ 43^s$(+) Corr. = 4.329^s
L. App. T., Dec. 31 = $21^h\ 26^m\ 0^s$
Mean time required = $21^h\ 29^m\ 43^s$
Or = Jan. 1, $9^h\ 29^m\ 43^s$ A. M. Ans.

Example 3.—The local apparent time June 22, 1899, is $5^h\ 42^m$ P. M. Find the mean time, the longitude being 100° 30′ E.

Solution.—L. App. T., June 22 = $5^h\ 42^m$ P. M.
Or, June 21 = $29^h\ 42^m$ P. M.
Long. (E) in time = $6^h\ 42^m$
G. D., June 21 = $23^h\ 0^m$

Equation of Time (App. Noon)

June 22	=	$1^m\ 42.1^s$
Change for 1^h	=	$-\ 0.54^s$
Corr. Eq. of T.	=	$1^m\ 41.56^s\ (+)$
L. App. T., June 22	=	$5^h\ 42^m\ 0^s$
Mean time required	=	$5^h\ 43^m\ 41.6^s$. Ans.

66. To Find the Sidereal Time Corresponding to a Certain Mean Time.—Let the circumference of each circle, Fig. 4, represent the celestial equator; mn the meridian; P the celestial pole; Υ the first point of Aries, or the vernal equinoctial point; M the mean sun situated to the west of the meridian mn; and M' the mean sun when situated to the

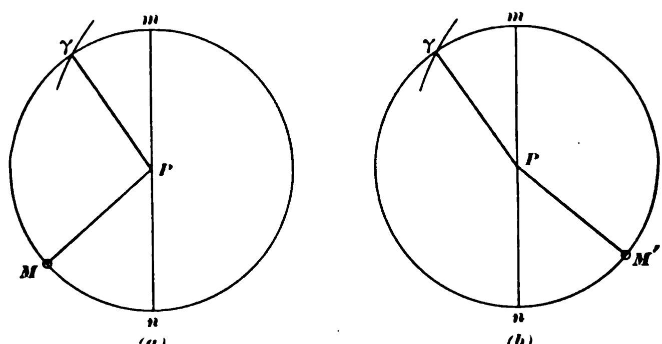


FIG. 4

east of the meridian mn. Then, the angle ΥPn will represent the sidereal time, as it is the hour angle of Υ, or it will represent the time since Υ was on the meridian; the angle MPn will represent the given mean time, being the hour angle of the mean sun; and the arc ΥM will represent the right ascension of the mean sun.

Then, in Fig. 4 (a),

sidereal time $\Upsilon n = \Upsilon M + Mn$,

or $\Upsilon n =$ R. A. M. S. + mean time

Also, in Fig. 4 (b),

$$\Upsilon n = \Upsilon M' - M'n$$

But, $M'n = 24^h -$ mean time

Hence, $\Upsilon n =$ R. A. M. S. $-$ ($24^h -$ mean time),

or $\Upsilon n =$ R. A. M. S. + mean time $- 24^h$

The sidereal time is therefore equal to the sum of the right ascension of the mean sun and the given mean time, 24 hours being subtracted from the result if over 24 hours. Hence, the procedure for finding the sidereal time when the mean time is known may be embodied in the following rule:

Rule.—*Find the Greenwich date. Find from the Nautical Almanac the right ascension of the mean sun according to Art.* **57**, *and add to it the given mean time. The sum, rejecting 24 hours, if over 24 hours, will be the required sidereal time.*

EXAMPLE 1.—The mean time of a ship in longitude 84° 35′ W, January 23, is 4^h 36^m A. M. Find the corresponding sidereal time.

SOLUTION.—

L. M. T., Jan. 22 =	16^h 36^m
Long. (W) in time =	5^h 38.3^m
G. D., Jan. 22 =	22^h 14.3^m
Sid. time G. M. N., Jan. 22 =	20^h 6^m 28.45^s
Table III, Corr. for 22^h 14.3^m =	3^m 39.2^s
R. A. M. S. =	20^h 10^m 7.65^s
L. M. T. =	16^h 36^m
Sid. time required =	36^h 46^m 7.7^s − 24^h
Or =	12^h 46^m 7.7^s. Ans.

EXAMPLE 2.—A ship is in longitude 75° 20′ E. About 1:20 P. M., February 26, 1899, the ship's chronometer indicated 8^h 14^m 31^s, its error on Greenwich mean time being 2^m 19^s slow. Required, the local sidereal time.

SOLUTION.—First find the local mean time at ship according to Art. **49**, and then the corresponding sidereal time. Thus,

Chron. =	8^h 14^m 31^s	
Error =	+ 2^m 19^s	
	8^h 16^m 50^s	
Add	12^h	(Art. **48**)
G. M. T., Feb. 25 =	20^h 16^m 50^s	= G. D.
Long. (E) in time =	+ 5^h 1^m 20^s	
	25^h 18^m 10^s	
L. M. T., Feb. 26 =	1^h 18^m 10^s	

Sid. time G. M. N., Feb. 25 =	22^h 20^m 31.32^s
Table III, Corr. for 20^h 17^m =	3^m 19.9^s
R. A. M. S. =	22^h 23^m 51.22^s
L. M. T. =	1^h 18^m 10^s
Sid. time required =	23^h 42^m 1^s. Ans.

67. If the given time is *apparent*, it must be reduced to *mean* time by the application of the equation of time, according to Art. **65.** The sidereal time is then found according to the rule of Art. **66.**

68. To Find the Mean Time Corresponding to a Given Sidereal Time.—There are several methods by which the mean time corresponding to a given sidereal time may be determined. Among these the following is selected as being simple and easily committed to memory.

In Art. **66** it was shown that

$$\text{sidereal time} = \text{R. A. M. S.} + \text{mean time}$$

Hence, $\text{mean time} = \text{sidereal time} - \text{R. A. M. S.},$

or $\text{mean time} = \text{sidereal time} + 24^h - \text{R. A. M. S.}$

Hence, *when the sidereal time is known, the corresponding mean time is readily obtained by subtracting from the given sidereal time (increased by 24^h if necessary) the right ascension of the mean sun.*

But, as the right ascension of the mean sun cannot be obtained before the mean time is known, an approximate value of the mean time must be found by using in the preceding formula the right ascension of the mean sun for the given day as tabulated in the Nautical Almanac. By applying to this approximate local mean time the longitude in time, an approximate Greenwich date is found, and from this a more correct value of the right ascension of the mean sun is obtained. This new value of the right ascension of the mean sun subtracted from the given sidereal time will produce a more correct value of the mean time, by means of which a still more correct value of the right ascension of the mean sun may be obtained. This procedure may be repeated until a desired degree of accuracy is arrived at; the second approximation, however, is quite sufficient for all practical purposes.

EXAMPLE 1.—On July 6, 1899, in longitude 124° 40′ W, the sidereal time is $7^h\ 24^m\ 48^s$. Find the corresponding mean time.

SOLUTION.—

Sid. time, July 6 =	$7^h 24^m 48^s$	R. A. M. S =	$6^h 57^m 0^s$
R. A. M. S. =	$-6^h 57^m 0^s$	Corr. for $8^h 46^m$, Table III, N. A. =	$1^m 26.4^s$
Approx. L. M. T. =	$0^h 27^m 48^s$		
Long. (W) in time =	$+8^h 18^m 40^s$	Corr. R. A. M. S. =	$6^h 58^m 26.4^s$
Approx. G. D., July 6 =	$8^h 46^m 28^s$		

Sid. time, July 6 =	$7^h 24^m 48^s$	R. A. M. S. =	$6^h 57^m 0^s$
Corr. R. A. M. S. =	$-6^h 58^m 26.5^s$	Corr. for $8^h 45^m$, Table III, N. A. =	$1^m 26.2^s$
Approx. L. M. T. =	$0^h 26^m 21.5^s$		
Long. (W) in time =	$+8^h 18^m 40^s$	2d Corr. R. A. M. S. =	$6^h 58^m 26.2^s$
2d Approx. G. D. =	$8^h 45^m 1.5^s$		

The second value of the right ascension of the mean sun differs only by $.2^s$ from that previously found; the required mean time is therefore $0^h 26^m 21^s$. Ans.

EXAMPLE 2.—On January 18, 1899, in longitude 174° 30′ E, the sidereal time is $19^h 26^m 14^s$. Required, the corresponding mean time.

SOLUTION.—

Sid. time, Jan. 18 =	$19^h 26^m 14^s$	R. A. M. S. =	$19^h 46^m 45.6^s$
Or, Jan. 17 =	$43^h 26^m 14^s$	Corr. for $12^h 1.5^m$, Table III, N. A. =	$1^m 58.5^s$
R. A. M. S. =	$-19^h 46^m 45.6^s$		
Approx. L. M. T. =	$23^h 39^m 28.4^s$	Corr. R. A. M. S. =	$19^h 48^m 44.1^s$
Long. (E) in time =	$-11^h 38^m 0^s$		
G. D., Jan. 17 =	$12^h 1^m 28.4^s$		

Sid. time, Jan. 17 =	$43^h 26^m 14^s$
Corr. R. A. M. S. =	$19^h 48^m 44^s$
L. M. T., Jan. 17 =	$23^h 37^m 30^s$
Or, Jan. 18 =	$11^h 37^m 30^s$ A. M. Ans.

69. In the foregoing examples it will be noticed that the corrections used are taken from Table III, Nautical Almanac, just as was done in the method for converting mean into sidereal time. The same result, however, may be obtained by using Table II of the Almanac and a slightly different method, as follows:

Find from the Almanac the right ascension of the mean sun for the given local astronomical day. Apply to this a correction for the longitude in time taken from Table III, Nautical Almanac, adding for west and subtracting for east longitude. Subtract the result from the local sidereal time (increased by 24 hours if necessary), and apply to the

remainder a correction taken from Table II of the Almanac. This correction is always subtractive. The result will be the required local mean time.

Applying this method to example 2, the solution will be as follows:

Long. 174° 30′ E = $11^h\ 38^m$ E

Sid. time, Jan. 18	= $19^h\ 26^m\ 14^s$	R. A. M. S.	= $19^h\ 46^m\ 45.6^s$
Or, Jan. 17	= $43^h\ 26^m\ 14^s$	Corr. for Long. (E) $11^h\ 38^m$, Table III	= − $1^m\ 54.7^s$
Corr. R. A. M. S.	= $19^h\ 44^m\ 51^s$		
Sid. interval	= $23^h\ 41^m\ 23^s$	Corr. R. A. M. S.	= $19^h\ 44^m\ 50.9^s$
Corr. Table II, N. A.	= − $3^m\ 53^s$		
L. M. T., Jan. 17	= $23^h\ 37^m\ 30^s$		

In this solution, the corrected R. A. M. S. is the right ascension of the mean sun at local mean noon, or the sidereal time of local mean noon. This subtracted from the given sidereal time gives the sidereal interval from local mean noon, which is then converted to mean time by the correction (corresponding to hours and minutes of this interval) taken from Table II of the Nautical Almanac.

70. When the apparent time corresponding to a given sidereal time is required, the mean time is first computed, as shown in the preceding examples; whence, the apparent time is found by applying the equation of time according to Art. **65**.

71. Remarks on Tables II and III of the Almanac. Table III at the end of the Nautical Almanac is essentially a table containing the factors for converting a mean time interval into a sidereal interval, and Table II, for converting a sidereal interval into a mean time interval. During a mean solar day, or 24 hours of mean time, sidereal time *gains* 3^m 56.5553^s; in 1 hour, therefore, it gains $\frac{3^m\ 56.5553^s}{24} = 9.8565^s$.

Table III is computed on the basis of this gain in order to facilitate the conversion of mean solar into sidereal time. Therefore, instead of multiplying the gain for each hour by the hours and fractions of the mean time interval, the product is taken direct from the table and added to the given interval.

Similarly with Table II. In a sidereal day, mean time *loses* on sidereal time $3^m\ 55.9094^s$, or 9.8296^s in an hour. This gradual and uniform loss is tabulated in Table II for each hour and minute of sidereal time; hence, when a sidereal interval is given, its reduction to mean time is readily accomplished by subtracting the loss taken from Table II corresponding to hours and minutes of the given sidereal interval. It must be borne in mind, however, that both tables are used only for converting one interval into another.

72. To Find What Bright Star Will Be on the Meridian at a Certain Mean or Apparent Time.—Let the circumference of the outer circle, Fig. 5, represent the celestial equator, P the celestial pole, $m\,n$ the observer's meridian, S a star crossing the meridian, ♈ the first point of Aries, and M the position of the mean sun. Then, it is evident that the angle ♈Pn, or the arc ♈n, which represents the right ascension of the star S, will, at the instant when the star is on the meridian, be equal to the right ascension of the observer's meridian. Now, Mn is the hour angle of the mean sun, or the mean time, and ♈M represents the right ascension of the mean sun; hence,

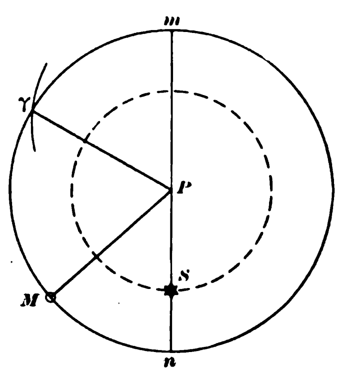


FIG. 5

♈n = R. A. of star = R. A. of meridian = ♈$M + Mn$,

or R. A. of star = R. A. M. S. + mean time

But, in Art. **66** it was shown that

R. A. M. S. + mean time = sidereal time

Therefore, *the right ascension of the star, or the right ascension of the meridian, is equivalent to sidereal time.*

From this, it is evident that in order to find how soon after a certain time, or at what time, a star will be on the meridian, it is simply necessary to find the sidereal time for the instant required, according to the rule of Art. **66.** The

sidereal time thus found will be the right ascension of the observer's meridian, and, consequently, the right ascension of any celestial body on the meridian. Hence, that star in the catalog of Fixed Stars in the Nautical Almanac whose right ascension is equal to that found, will be on the meridian at the given time; or, if there is no star with that right ascension, the one whose right ascension is *next greater* will be the first to pass the meridian after the given time.

EXAMPLE 1.—What bright star will pass the meridian of a ship in longitude 30° W at, or nearest after, 10:30 P. M, local mean time, on October 10, 1899?

SOLUTION.—

L. M. T., Oct. 10 =	$10^h\ 30^m$
Long. (W) in time =	$+\ 2^h\ 0^m$
G. D., Oct. 10 =	$12^h\ 30^m$
Sid. time G. M. N., Oct. 10 =	$13^h\ 15^m\ 29.3^s$
Table III, Corr. for $12^h\ 30^m$ =	$2^m\ 3.2^s$
R. A. M. S. =	$13^h\ 17^m\ 32.5^s$
L. M. T. =	$10^h\ 30^m\ 0^s$
Sid. time, or R. A. of Mer. =	$23^h\ 47^m\ 32.5^s$

Examining the catalog of Fixed Stars in the Nautical Almanac for a star whose right ascension is equal to the sidereal time found, ω Piscium is found to be the nearest; but since this star is only of the fourth magnitude, and hence too small to be observed by means of a sextant, it is necessary to look further until a bright star, that is, a star of the first or second magnitude, whose right ascension is next greater than $23^h\ 47^m$, is found. The star Alpha in the constellation Andromeda, whose right ascension is $0^h\ 3^m\ 10^s$ (or $24^h\ 3^m\ 10^s$), and whose magnitude is sufficiently great to render it observable with a sextant, is therefore the star required, and this star will be the first bright star to pass the observer's meridian next after 10:30 P. M., Oct. 10. Ans.

EXAMPLE 2.—What bright star will be the first to pass the meridian of a ship in longitude 15° 30′ W, after 11 P. M., apparent time, April 25, 1899?

SOLUTION.—

L. App. T., Apr. 25 =	$11^h\ 0^m\ 0^s$
Approx. Eq. of T. =	$2^m\ 5^s(-)$
L. M. T. =	$10^h\ 57^m\ 55^s$
Long. (W) in time =	$+\ 1^h\ 2^m\ 0^s$
G. D., Apr. 25 =	$11^h\ 59^m\ 55^s$

Sid. time G. M. N., Apr. 25 =	$2^h\ 13^m\ 8^s$
Corr. for 12^h =	$1^m\ 58^s$
R. A. M. S. =	$2^h\ 15^m\ 6^s$
L. M. T. =	$10^h\ 57^m\ 55^s$
Sid. time, or R. A. of Mer. =	$13^h\ 13^m\ 1^s$

By examining the catalog of Fixed Stars in the Nautical Almanac it is found that the star that will be on the meridian next after this time is the Spica (α Virginis), whose right ascension is $13^h\ 19^m\ 52^s$. Ans.

73. From Fig. 5, it is evident that all stars whose right ascensions are greater than that of the meridian must be to the *eastward*, and all stars whose right ascensions are less must be to the *westward*, of the observer's meridian.

74. To Find What Bright Stars Will Be on the Meridian Between Two Given Times.—It may often be desirable to know what bright stars will be on the observer's meridian between two given times. This is readily determined by finding the right ascension of the meridian, or the sidereal time corresponding to each of the given times, as shown in Art. **72**; then, all the stars in the catalog of Fixed Stars whose right ascension lies between the sidereal times thus determined will cross the meridian between the two given times.

EXAMPLE.—Find what bright stars will cross the meridian of a ship in longitude 90° W between the hours of 10 and 12 P. M., October 3, 1899.

SOLUTION.—

L. M. T. =	10^h	Sid. time G. M. N. =	$12^h\ 47^m\ 53^s$
Long. (W) in time =	$+\ 6^h$	Corr. for 16^h =	$+\ \ 2^m\ 38^s$
G. D., Oct. 3 =	16^h	R. A. M. S. =	$12^h\ 50^m\ 31^s$
		L. M. T. =	10^h
		Sid. time Corres. to 10^h P. M. =	$22^h\ 50^m\ 31^s$
L. M. T. =	12^h	Sid. time G. M. N. =	$12^h\ 47^m\ 53^s$
Long. (W) in time =	$+\ 6^h$	Corr. for 18^h =	$+\ \ 2^m\ 57^s$
G. D., Oct. 3 =	18^h	R. A. M. S. =	$12^h\ 50^m\ 50^s$
		L. M. T. =	12^h
		Sid. time Corres. to 12^h P. M. =	$0^h\ 50^m\ 50^s$

Examining the star catalog it is found that the bright stars whose right ascension lies between $22^h\ 50^m$ and $0^h\ 50^m$ are as follows:

α Pis. Aust., *Fomalhaut;*
α Pegasi, *Markab;*
α Andromedæ;
β Cassiopeiæ;
α Cassiopeiæ;
β Ceti; and
γ Cassiopeiæ.

All of these stars will therefore cross the meridian of the ship between 10 and 12 P. M. Ans.

NOTE.—Stars that are thus calculated to be on the meridian will not necessarily be available for observation. This condition, which depends on the latitude and the declination of the star, will be considered later on in connection with the method of finding the latitude by a meridian altitude of a fixed star.

75. To Find the Time When a Certain Star Will Be on the Meridian.—In Art. **72**, it was shown that

R. A. M. S. + mean time = R. A. of meridian = R. A. of star

Solving for mean time,

mean time = R. A. of star − R. A. M. S.

Hence, the mean time when a certain star will be on the meridian is found by subtracting the right ascension of the mean sun from the right ascension of the star, increased, if necessary, by 24 hours, the right ascension of the mean sun being corrected to any desired degree of accuracy.

EXAMPLE.—Find what time the star Sirius (α Canis Majoris) will be on the meridian of a ship in longitude 68° 30′ W, November 21, 1899.

SOLUTION.—	✳ R. A. + 24^h =	$30^h\ 40^m\ 42^s$
	Sid. time G. M. N., or R. A. M. S. =	− $15^h\ 57^m\ 8^s$
	Approx. L. M. T. =	$14^h\ 43^m\ 34^s$
	Long. (W) in time =	+ $4^h\ 34^m\ 0^s$
	Approx. G. D., Nov. 20 =	$19^h\ 17^m\ 34^s$
	Sid. time G. M. N., Nov. 20 =	$15^h\ 57^m\ 8^s$
	Table III, Corr. for $19^h\ 18^m$ =	$3^m\ 10.2^s$
	R. A. M. S =	$16^h\ 0^m\ 18.2^s$
	✳ R. A. =	$30^h\ 40^m\ 42^s$
	L. M. T. of ✳ transit =	$14^h\ 40^m\ 24^s$

Hence, the star will be on the meridian of the ship at $14^h\ 40^m\ 24^s$, Nov. 20, or at $2^h\ 40^m\ 24^s$ A. M. on Nov. 21. Ans.

76. In the preceding example, the approximate mean time of the star's transition is obtained by subtracting the right ascension of the mean sun from that of the star

increased by 24 hours, whence the approximate Greenwich date is obtained by applying the longitude in time. Then, by applying a correction for the hours and minutes of the Greenwich date, a more exact value of the right ascension of the mean sun is obtained (compare Art. **68**), which, when subtracted from the right ascension of the star, will give the local mean time of the star's transit or meridian passage.

EXAMPLE 1.—At what time will the star Regulus (*α* Leonis) be on the meridian of a ship in longitude 115° 48′ E, December 30, 1899?

SOLUTION.—

✳ R. A. + 24^h =	$34^h\ 2^m\ 59.6^s$
Sid. time G. M. N., or R. A. M. S. =	$-\ 18^h\ 30^m\ 53.8^s$
Approx. L. M. T. =	$15^h\ 32^m\ 5.8^s$
Long. (E) in time =	$-\ 7^h\ 43^m\ 12^s$
G. D., Dec. 29 =	$7^h\ 48^m\ 53.8^s$
Sid. time G. M. N., Dec. 29 =	$18^h\ 30^m\ 53.8^s$
Table III, Corr. for $7^h\ 49^m$ =	$1^m\ 17^s$
R. A. M. S. =	$18^h\ 32^m\ 10.8^s$
✳ R. A. =	$34^h\ 2^m\ 59.6^s$
L. M. T. of ✳ transit, Dec. 29 =	$15^h\ 30^m\ 48.8^s$ P. M.
Or, Dec. 30 =	$3^h\ 30.8^m$ A. M. Ans.

EXAMPLE 2.—At what time will the star Antares (*α* Scorpii) be on the meridian of Leghorn, Italy (longitude 10° E), on August 5, 1899?

SOLUTION.—

✳ R. A. =	$16^h\ 23^m\ 12.8^s$
Sid. time G. M. N. =	$-\ 8^h\ 55^m\ 16.7^s$
Approx. L. M. T. =	$7^h\ 27^m\ 56^s$
Long. (E) in time =	$-\ 0^h\ 40^m\ 0^s$
G. D., Aug. 5 =	$6^h\ 47^m\ 56^s$
Sid. time G. M. N., Aug. 5 =	$8^h\ 55^m\ 16.7^s$
Table III, Corr. for $6^h\ 48^m$ =	$1^m\ 7^s$
R. A. M. S. =	$8^h\ 56^m\ 23.7^s$
✳ R. A. =	$16^h\ 23^m\ 12.8^s$
L. M. T. of ✳ transit, Aug. 5 =	$7^h\ 26^m\ 49^s$ P. M. Ans.

NOTE.—Since the difference between these two values of the mean time does not amount to more than 2 or 3 minutes, it may, for most practical purposes, be considered sufficiently correct, in determining the mean time when a star will be on the meridian, to subtract the right ascension of the mean sun, or sidereal time at Greenwich mean noon, *without correction* from the right ascension of the star.

77. To Find, Approximately, the Apparent Time of a Star's Meridian Passage.—It is evident that when the mean time of a star's meridian passage is known, the

corresponding apparent time is found by applying the equation of time taken out and corrected for the Greenwich date; or, the approximate apparent time of a star's meridian passage may be found directly by the following rule:

Rule.—*From the right ascension of the star subtract the right ascension of the true sun, as found in the Nautical Almanac on the page marked I; the remainder is the approximate apparent time of the star's meridian passage.*

EXAMPLE 1.—Find the apparent time of the meridian passage of Fomalhaut (α Pis. Aust.) on October 8, 1899.

SOLUTION.—

$$\begin{aligned} \text{✱ R. A.} &= 22^h\ 52^m\ 4^s \\ \odot\ \text{R. A.} &= -12^h\ 55^m\ 9^s \\ \hline \text{App. time of ✱ transit} &= 9^h\ 56^m\ 55^s\ \text{P. M.}\quad \text{Ans.} \end{aligned}$$

EXAMPLE 2.—Find the apparent time of the meridian passage of Rigel (β Orionis) on September 6, 1899.

SOLUTION.—

$$\begin{aligned} \text{✱ R. A.} + 24^h &= 29^h\ 9^m\ 41^s \\ \odot\ \text{R. A.} &= 10^h\ 59^m\ 44^s \\ \hline \text{App. time of transit} &= 18^h\ 9^m\ 57^s \\ \text{Or} &= 6^h\ 9^m\ 57^s\ \text{A. M.}\quad \text{Ans.} \end{aligned}$$

NOTE.—For observations at sea, it is advisable to select a star whose transit occurs during the morning or evening twilight, because then the sea horizon is well defined and the result will therefore be more trustworthy.

78. The preceding articles relating to the transitions of stars apply to the meridian passage *above* the pole, or when the celestial body is situated at S, Fig. 6, P being the celestial pole. To obtain the time of transit when the star is on the meridian $m\,n$ *below* the pole, or at S', 12 sidereal hours ($= 11^h\ 58^m\ 2^s$ mean time) is added to the time given for the upper transit. For any celestial object, it can be shown that the mean time of lower meridian passage is equal to (12^h + right ascension of object) − right ascension of the mean sun.

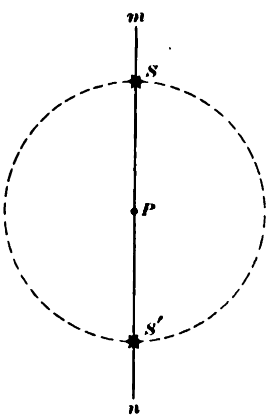


FIG. 6

It is evident that the rules given for determining the time of the meridian passage of stars

are applicable also to the planets; but, since the apparent motion of the planets is irregular, it is more convenient to find the time of their transits according to instructions given in Art. **64.**

79. Cautionary Remarks.—In dealing with times of meridian passage at sea, it is well to remember that the ship's clocks that are regulated at each noon, when observations of the sun are taken, show correct apparent time at that instant only; also, that these clocks will be too fast if the ship sails westward from noon to the time of observation, and too slow if the ship sails eastward, by 4 minutes of time for every degree of longitude traversed. Hence, when the apparent time for a star's transit is determined, an appropriate allowance should be made for the ship's run by *adding* 4 minutes of time for each degree of longitude sailed eastward, or by *subtracting* the same number of minutes for every degree of longitude sailed westward.

EXAMPLES FOR PRACTICE

1. The local apparent time of a place in longitude 81° 15′ E, April 3, 1899, is $8^h\ 45^m$ A. M. Required, the corresponding mean time.
Ans. L. M. T., Apr. 3 = $8^h\ 48^m\ 27.5^s$ A. M.

2. The mean time at a ship in longitude 81° 15′ W, April 21, 1899, is $3^h\ 5^m$ P. M. Find the corresponding apparent time.
Ans. L. App. T., Apr. 21 = $3^h\ 6^m\ 22.9^s$

3. The mean time at a ship in longitude 36° 30′ E, June 20, 1899, is $1^h\ 40^m\ 42^s$ P. M. Find the sidereal time.
Ans. Sid. time = $7^h\ 34^m\ 29.7^s$

4. The Greenwich mean time August 1, 1899, is $5^h\ 15^m\ 25^s$. Find the corresponding local sidereal time at a ship in longitude 124° 37′ W.
Ans. L. Sid. time = $5^h\ 37^m\ 19.3^s$

5. On January '18, 1899, in longitude 174° 30′ E, a sidereal clock indicated $19^h\ 26^m\ 14^s$. Find the corresponding local mean time.
Ans. L. M. T., Jan. 18 = $11^h\ 37^m\ 30^s$ A. M.

6. Find what bright star was the next to pass the meridian after midnight December 2, 1899, at a place in longitude 30 W.
Ans. Capella (α Aurigæ)

7. Find, approximately, the apparent time of meridian passage of the star Vega (α Lyræ) on June 30, 1899. Ans. $11^h\ 56.8^m$ P. M.

8. What stars of the first magnitude will cross the meridian of an observer in longitude 124° 30′ E between 8:30 and 9:30 P. M. on March 2, 1899?

Ans. Procyon (α Canis Minoris)
Pollux (β Geminorum)

LATITUDE

DETERMINATION OF LATITUDE

LATITUDE BY MERIDIAN ALTITUDE

1. The simplest and most reliable method of determining the latitude of a ship at sea is that deduced from an observed *meridian altitude* of a celestial body. Three distinct reasons may be put forth in support of this statement: first, that the measurement of a meridian altitude of a celestial body, particularly the sun, can, as a general rule, be made with the utmost accuracy; second, that an error in the estimated longitude and, consequently, in the time, has no appreciable effect on the resulting latitude; third, that the necessary calculations are few and simple.

2. Desirable Objects for Latitude Observations. The most desirable object to select for latitude observations is the *sun*, which is on the meridian of the ship at apparent noon each day. Hence, when the weather permits, the opportunity of measuring the sun's altitude at that instant should never be disregarded at sea.

A star of known declination is also a very suitable object provided the observer has sufficient training in measuring altitudes at night. With the star's appearance, the sea horizon generally becomes too obscure to be sufficiently well defined, and, as a rule, it requires considerable practice before altitudes of stars as measured from the sea horizon can be considered trustworthy. It goes without saying that only stars of the first and second magnitudes should be used for

this purpose. Quite satisfactory results from the observation of such stars are usually attained by skilled observers.

The moon, on the other hand, is not so well adapted for determining the latitude by its meridian altitude as are the sun and the stars. Owing to the rapid change of the moon's declination, the longitude and, thus, the time must be known quite accurately. If the error in the time is considerable, there will be a proportionate error in the declination, and, consequently, in the latitude found, since the declinations of the observed body, as well as its meridian altitude, are the very data from which the latitude is derived. Hence, when an uncertainty in longitude or Greenwich time exists, the moon should not be used in determining the latitude. In such cases, the stars are more preferable, since their declination may be considered as constant or nearly so. Likewise, the sun is much to be preferred to the moon, since the declination of the sun varies so slowly that even a considerable error in the ship's longitude, and, therefore, in the Greenwich time, will occasion no error of consequence in the declination at the time of observation.

3. Elements Involved.—Before considering the method of determining latitude by a meridian altitude, it will be well to consider once more the elements involved, so that no misunderstanding may exist as to their meaning. The elements referred to are meridian altitude, zenith distance, and declination.

1. *Meridian altitude* is the highest altitude attained by a celestial body during its passage across the visible heavens; it is the altitude reached when the body is crossing the meridian of the observer. As stated before, the meridian passes through the observer's zenith and the north and south points of the horizon. Hence, when a celestial body—for instance, the sun—is on the meridian, which occurs at noon each day, it bears exactly south or north, as the case may be, depending on whether the observer is in a north or a south latitude. In any part of the world, above latitude 24° N, the sun always bears south when on the meridian. In Fig. 1, if Z is the

zenith of the observer, and S is the south, E the east, and W the west point of the horizon, then the line SZ will represent the meridian of the observer stationed at o. When the sun, in its daily circuit from east to west, reaches this line, it is said to be on the meridian, and its altitude Sc at that time (noon) is the meridian altitude used in finding the latitude.

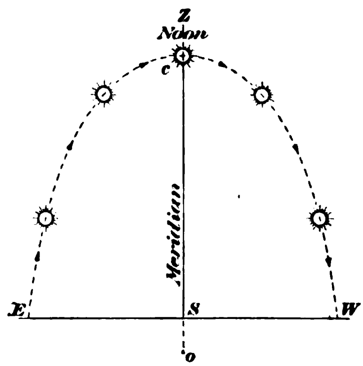


FIG. 1

2. The *zenith distance* (denoted by Z. D.) is the complement of the true altitude; it is either north or south and is named accordingly. If the observer faces north when measur-

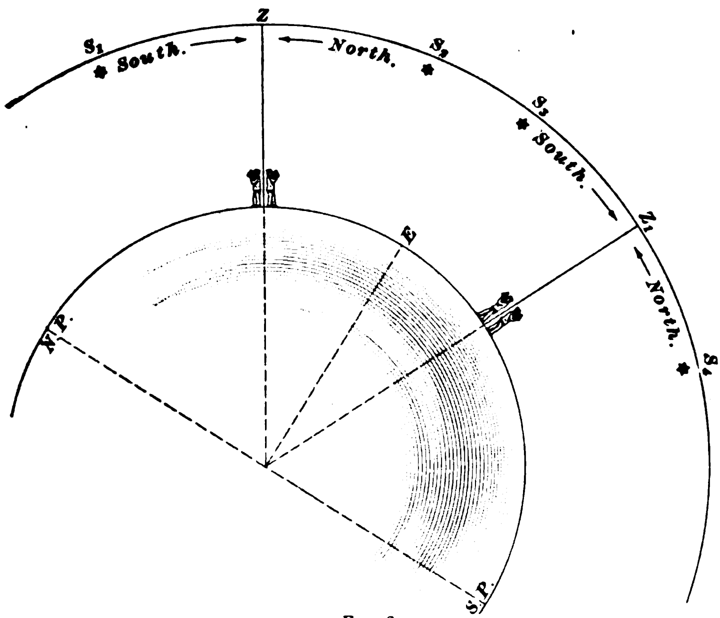


FIG. 2

ing the altitude, the zenith distance is south; if the observer faces south, the zenith distance is north. Thus, in Fig. 2, if

the observer's zenith is at Z, the zenith distance $S_1 Z$ of the star S_1 is south, and the zenith distance $S_2 Z$ of the star S_2 is north. If the observer's zenith is at Z_1, the zenith distance $S_3 Z_1$ of the star S_3 is south, and the zenith distance $S_4 Z_1$ of the star S_4 is north. In the figure are shown the different positions of an observer in both south and north latitudes, illustrating graphically how the zenith distance is named.

3. Finally, there is the *declination* of the observed body. As already stated, the declinations of the sun, moon, and stars are tabulated in the Nautical Almanac. Great care should be taken in finding the declination of the moon on account of its rapid change, and the instructions given on that subject in a previous Section should be closely followed. In regard to the sun, it well to bear in mind that its declination never exceeds 23° 27′ 30″ north or south. On March 21 or 22, the sun is on the equator and its declination is zero. From this date to June 21, the sun's declination is *north* and *increasing;* from June 21 to September 22 or 23, it is *north* and *decreasing*. On September 22 or 23, the sun is again on the equator and its declination is zero. From this date to December 21, the sun's declination is *south* and *increasing;* and from December 21 to March 22, it is *south* and *decreasing*. The declination of the stars is practically stationary, and, for nautical purposes, it is picked out and used as found in the Nautical Almanac.

4. General Formula for Latitude.—The general formula for finding the latitude from an observed meridian altitude of celestial body at its upper transit is

$$\text{latitude} = \text{zenith distance} \pm \text{declination}$$

In Fig. 3, let $epe'p'$ represent the earth, o the position of an observer on its surface, ee' the equator, p the elevated pole (in this case the north pole), HH' the rational horizon, EE' the celestial equator, P the celestial pole, and Z the zenith of the observer stationed at o. Now, the latitude of any place on the earth is defined as the arc of the meridian intercepted between the equator and the place. In this case, therefore, the latitude of the observer at o is the arc eo of

the meridian pep'; this arc eo is evidently equal to the arc EZ on the celestial sphere. Assume that a celestial body, for instance a star, is situated at S. The arc HS is then the true altitude of that star, ZS is the zenith distance, and ES is the declination. Since both the declination and the zenith distance of the star are north, it is evident that the latitude eo ($= EZ$) is equal to $ZS + ES$, or

$$\text{latitude} = \text{zenith distance} + \text{declination}$$

If the celestial body is situated at S_1, the arc ZS_1 will be its zenith distance and ES_1 its declination. The former

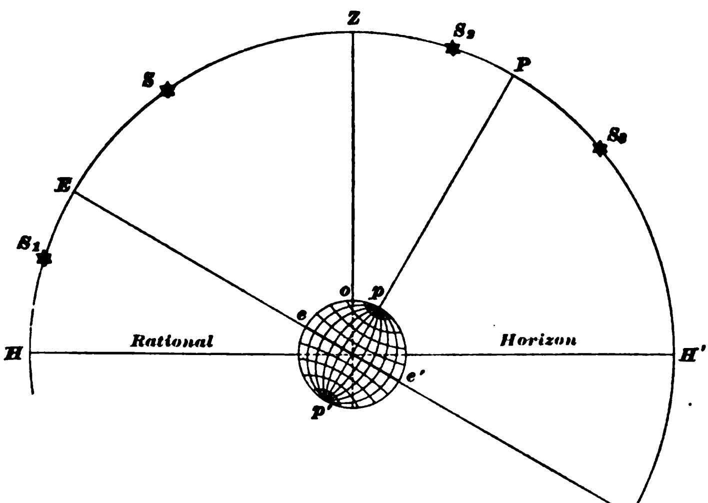


Fig. 3

being north and the latter south, the latitude eo ($= EZ$) is, in this case, equal to $ZS_1 - ES_1$, or

$$\text{latitude} = \text{zenith distance} - \text{declination}$$

Again, if the star is situated at S_2, the arc ES_2 will be its declination (northerly) and ZS_2 its zenith distance (southerly). In this case, therefore, the latitude eo or the arc EZ is equal to $ES_2 - ZS_2$, or

$$\text{latitude} = \text{declination} - \text{zenith distance}$$

All of these cases apply to a celestial body when on the meridian *above the pole*. The general formula, therefore, for

finding the latitude from an observed meridian altitude above the pole is

$$\text{latitude} = \text{zenith distance} \pm \text{declination},$$

which expression may be embodied in the following rule:

Rule.—*Add the zenith distance and the declination when they are of the same name, but subtract the smaller quantity from the larger when they are of different names. The result is the latitude, which has the same name as the larger quantity.*

5. Meridian Altitudes at Lower Transit.—To find the latitude by a meridian altitude when the observed body is *below the pole*, or at its lower meridian passage, reference is again made to Fig. 3, where the arc EP is equal to ZH', both being 90°. By subtracting the arc ZP from both, it is evident that the remainder EZ is equal to PH'; but $EZ = eo =$ latitude, and PH' is equal to the elevation of the pole above the horizon. From this an important fact is established; namely, *the latitude of any place on the earth is equal to the true latitude of the pole above the horizon.* If, therefore, the observed body is situated at S_3, below the pole, PS_3 being its polar distance and S_3H' its true latitude, the latitude eo $(= EZ = PH')$ is evidently equal to $PS_3 + S_3H'$, or

$$\text{latitude} = \text{polar distance} + \text{true altitude}$$

But the polar distance (denoted by P. D.) is the complement of declination, or 90° − declination. Hence, when the observed body is on the meridian below the pole, then

$$\text{latitude} = 90° + \text{true meridian altitude} - \text{declination},$$

the result having the same name as the declination of the observed body.

6. Circumpolar Stars.—Stars whose upper and lower meridian passages occur above the horizon are called **circumpolar.** From Fig. 3, it is evident that any celestial body whose polar distance is less than the latitude is circumpolar.

NOTE.—It is well to remember that when a celestial body is crossing the meridian *above* the pole it moves from east to west, and when crossing *below* the pole it moves from west to east.

LATITUDE BY A MERIDIAN ALTITUDE OF THE SUN

7. Directions.—Begin to measure the sun's altitude a short time, say 10 or 15 minutes, before noon, following the instructions given in a previous Section. The altitude will increase slowly until noon, when it will stop and begin to decrease. *The highest altitude attained is the required meridian altitude.* In measuring the altitude, be sure to have the lower limb of the sun in perfect contact with the sea horizon vertically below the sun. Whenever the limb seems to have lifted a trifle above the horizon, bring it down by a slight turn of the tangent screw. When no further upward movement of the sun is perceptible, it is noon (eight bells), and neither the tangent nor the clamp screw of the sextant should be touched until the altitude is read off. To make sure that the highest altitude is measured, it is advisable to wait a few minutes until the limb can be seen slightly below the horizon line. The sun has then culminated and begun to descend. On account of its slow horizontal movement when on the meridian (see *c*, Fig. 1), the sun may remain apparently stationary for several minutes before its downward motion is seen.

8. After the observed altitude is read, find the true altitude by applying corrections for index error, dip, semi-diameter, refraction, and parallax. Subtract the true altitude thus found from 90°; the result is the zenith distance, which is named north if observer was facing south, and south if he faced north when observing. Find, from the Nautical Almanac, the declination of the sun and correct it according to the preceding instructions. If the declination and the zenith distance have the same name, add them; if they have different names, subtract the smaller from the larger, according to the rule previously given. The result, named from the larger quantity, is the required latitude of the ship. In working out the latitude it will be found convenient to arrange the calculations as shown in the following examples. The declination, dip, and semi-diameter may be taken out beforehand ready for application.

Example 1.—On September 23, 1899, in longitude 11° 45′ W, by dead reckoning, the observed meridian altitude of the sun's lower limb was 33° 44′ 40″, the observer facing south. Index error = − 5′ 15″. Height of eye = 23 feet. Find the latitude.

Solution.—

$$
\begin{array}{rl}
\text{L. App. T., Sept. 23} = & 0^h\ 0^m\ 0^s \\
\text{Long. (W) in time} = & 0^h\ 47^m\ 0^s \\
\hline
\text{G. D., Sept. 23} = & 0^h\ 47^m\ 0^s
\end{array}
$$

$$
\begin{array}{rl@{\qquad}rr}
\odot\ \text{Decl., Sept. 23} = & \text{S } 0°\ 5'\ 13.9'' & \text{Change in } 1^h = & 58.4'' \\
\text{Corr. for } 47^m = & +\quad 46.7'' & & \times\ 0.8^h \\
\hline
\text{Corr. Decl.} = & \text{S } 0°\ 6'\ 0.6'' & \text{Corr.} = & 46.72''
\end{array}
$$

$$
\begin{array}{rl}
\text{Obs. Mer. Alt. } \underline{\odot} = & 33°\ 44'\ 40'' \\
\text{I. E.} = & -\quad 5'\ 15'' \\
\hline
 & 33°\ 39'\ 25'' \\
\text{Dip} = & -\quad 4'\ 42'' \\
\hline
\text{App. Alt. } \underline{\odot} = & 33°\ 34'\ 43'' \\
\odot\ \text{S. D.} = & +\quad 15'\ 59'' \\
\hline
\text{App. Alt. } \ominus = & 33°\ 50'\ 42'' \\
\text{Ref.} = & -\quad 1'\ 26'' \\
\hline
 & 33°\ 49'\ 16'' \\
\odot\ \text{Par.} = & +\quad 0'\ 7'' \\
\hline
\text{True Mer. Alt.} = & 33°\ 49'\ 23'' \\
 & 90°\ 0'\ 0'' \\
\hline
\text{Z. D.} = & 56°\ 10'\ 37''\ \text{N} \\
\odot\ \text{Decl.} = & 0°\ 6'\ .6''\ \text{S} \\
\hline
\text{Lat. required} = & 56°\ 4'\ 36.4''\ \text{N.}\quad \text{Ans.}
\end{array}
$$

In this case, the bearing of the sun being south, the zenith distance is north; the declination being south, the latitude is therefore equal to the difference between the two, and has the same name as the larger quantity.

Example 2.—On January 1, 1899, in longitude 49° E, the observed meridian altitude of the sun's upper limb was 76° 54′ 40″, the observer facing south. Index error = − 5′ 10″. Height of eye = 25 feet. Find the latitude.

Solution.—

$$
\begin{array}{rl}
\text{L. App. T., Jan. 1} = & 0^h\ 0^m\ 0^s \\
\text{Long. (E) in time} = & 3^h\ 16^m\ 0^s \\
\hline
\text{G. D., Dec. 31} = & 20^h\ 44^m\ 0^s
\end{array}
$$

$$
\begin{array}{rl@{\qquad}rr}
\odot\ \text{Decl., Jan. 1} = & \text{S } 23°\ 0'\ 14'' & \text{Change in } 1^h = & 12.5'' \\
\text{Corr. for } 3.3^h = & +\quad 41'' & & \times\ 3.3^h \\
\hline
\text{Corr. Decl.} = & \text{S } 23°\ 0'\ 55'' & \text{Corr.} = & 41.25''
\end{array}
$$

Obs. Mer. Alt. $\bar{\odot}$ = 76° 54′ 40″
I. E. = − 5′ 10″
76° 49′ 30″
Dip = − 4′ 54″
App. Alt. $\bar{\odot}$ = 76° 44′ 36″
$\odot$ S. D. = − 16′ 18″
App. Alt. $\ominus$ = 76° 28′ 18″
Ref. = − 0′ 13″
True Mer. Alt. = 76° 28′ 5″
90° 0′ 0″
Z. D. = 13° 31′ 55″ N
$\odot$ Decl. = 23° 0′ 55″ S
Lat. required = 9° 29′ 0″ S. Ans.

Example 3.—On September 22, 1899, in longitude 179° 15′ W, by dead reckoning, the sun's meridian altitude, lower limb, as observed in an artificial horizon, was 81° 17′ 50″, the observer facing south. Index error = − 2′ 2″. Required, the latitude.

Solution.— L. App. T., Sept. 22 = 0^h 0^m 0^s
Long. (W) in time = 11^h 57^m 0^s
G. D., Sept. 22 = 11^h 57^m 0^s

$\odot$ Decl., Sept. 22 = N 0° 18′ 8.7″
Corr. for 11.9^h = − 11′ 34.9″
Corr. Decl. = N 0° 6′ 33.8″

Change in 1 = 58.4″
× 11.9^h
Corr. = 694.96″
Or = 11′ 34.9″

Obs. double Mer. Alt. $\underline{\odot}$ = 81° 17′ 50″
I. E. = − 2′ 2″
2)81° 15′ 48″
App. Alt. $\underline{\odot}$ = 40° 37′ 54″
$\odot$ S. D. = + 15′ 59″
App. Alt. $\ominus$ = 40° 53′ 53″
Ref. = − 1′ 5″
40° 52′ 48″
$\odot$ Par. = + 0′ 7″
True Mer. Alt. = 40° 52′ 55″
90° 0′ 0″
Z. D. = 49° 7′ 5″ N
$\odot$ Decl. = 0° 6′ 34″ N
Lat. required = 49° 13′ 39″ N. Ans.

EXAMPLE 4.—On June 21, 1899, in longitude 120° 30′ E, by dead reckoning, the observed meridian altitude of the sun's lower limb was 16° 5′ 10″, the observer facing north. Index error = − 4′ 25″. Height of eye = 38 feet. Find the latitude.

SOLUTION.—

L. App. T., June 21	=	$0^h\ 0^m\ 0^s$
Long. (E) in time	=	$8^h\ 2^m\ 0^s$
G. D., June 20	=	$15^h\ 58^m\ 0^s$

⊙ Decl., June 21	=	N 23° 27′ 7″	Change in 1^h	=	0.17″
Corr. for 8^h	=	− 1″			$\times 8^h$
Corr. Decl.	=	N 23° 27′ 6″	Corr.	=	1.36″

Obs. Mer. Alt. ⊙̲	=	16° 5′ 10″
I. E.	=	− 4′ 25″
		16° 0′ 45″
Dip	=	− 6′ 3″
App. Alt. ⊙̲	=	15° 54′ 42″
⊙ S. D.	=	+ 15′ 46″
App. Alt. ⊖	=	16° 10′ 28″
Ref.	=	− 3′ 18″
		16° 7′ 10″
⊙ Par.	=	+ 0′ 8″
True Mer. Alt.	=	16° 7′ 18″
		90° 0′ 0″
Z. D.	=	73° 52′ 42″ S
⊙ Decl.	=	23° 27′ 6″ N
Lat. required	=	50° 25′ 36″ S. Ans.

9. Application of Corrections.—It is evident that in computing the latitude by a meridian altitude of the sun, or *noon sight*, as it is sometimes termed, as well as correcting altitudes in general, several short cuts may be used. For instance, the algebraic sum of all corrections may be taken, thus reducing them to one single correction, ready to be applied to the observed altitude when read off from the sextant. The declination may also be taken out and corrected beforehand, especially in cases where the longitude in at noon may be estimated with a fair degree of accuracy. In fact, an experienced observer having these data prearranged may calculate the

latitude *mentally* immediately after his observed meridian altitude is read off.

In the preceding example, for instance, the algebraic sum of all correction is as follows:

$$\begin{array}{rrl}
\text{I. E.} & = & -\ \ 4'\ 25'' \\
\text{Dip} & = & -\ \ 6'\ \ 3'' \\
\text{S. D.} & = & +\ 15'\ 46'' \\
\text{Ref.} & = & -\ \ 3'\ 18'' \\
\text{Par.} & = & \underline{+\ \ 0'\ \ 8''} \\
\text{Algebraic sum} & = & +\ \ 2'\ \ 8'' = \text{total correction}
\end{array}$$

The total correction, therefore, to be applied to the observed altitude is + 2′ 8″. The solution will then appear in the following abbreviated form:

$$\begin{array}{rrl}
\text{Obs. Alt.} & = & 16^\circ\ \ 5'\ 10'' \\
\text{Corr.} & = & \underline{+\ \ \ \ \ \ 2'\ \ 8''} \\
\text{True Alt.} & = & 16^\circ\ \ 7'\ 18'' \\
\text{Z. D.} & = & 73^\circ\ 52'\ 42''\ \text{S} \\
\text{Decl.} & = & \underline{23^\circ\ 27'\ \ 6''\ \text{N}} \\
\text{Lat.} & = & 50^\circ\ 25'\ 36''\ \text{S}
\end{array}$$

To reduce, in this manner, all corrections to a single correction, an approximate value of the meridian altitude must be known beforehand, in order to get a comparatively correct value of the refraction.

10. Use of Constants and Their Effect on Latitude. When using a single correction in reducing the observed altitude to true, as shown, be careful to use the algebraic sum of *all* corrections corresponding to the measured altitude. Guard against the bad practice of using a certain constant correction for all observed altitudes. Quite a number of shipmasters and officers use a constant of + 12′ as a substitute for dip, semi-diameter, refraction, and parallax, and apply this constant whether the observed altitude is 15° or 89°. Such a proceeding may seem very convenient, and, no doubt is, but it is entirely wrong and should never be

resorted to by a careful navigator. To illustrate the inaccuracy of this practice and its effect on the resulting latitude, apply this constant in the last example. Thus,

Obs. Alt.	=	16° 5′ 10″
I. E.	=	− 4′ 25″
		16° 0′ 45″
Constant	=	+ 12′ 0″
True Mer. Alt.	=	16° 12′ 45″
Z. D.	=	73° 47′ 15″ S
Decl.	=	23° 27′ 6″ N
Wrong Lat.	=	50° 20′ 9″ S
Corr. Lat.	=	50° 25′ 36″ S
Error	=	5′ 27″

It should be noted that by the use of this constant as a substitute for the regular corrections, the resulting latitude is $5\frac{1}{2}$ miles in error.

Suppose, now, that the upper limb of the sun has been measured as in example 2, and that the observer, as a matter of habit, applies the same constant. The result will be as follows:

Obs. Alt.	=	76° 54′ 40″
I. E.	=	− 5′ 10″
		76° 49′ 30″
Constant	=	+ 12′ 0″
True Mer. Alt.	=	77° 1′ 30″
Z. D.	=	12° 58′ 30″ N
Decl.	=	23° 26′ 28″ N
Wrong Lat.	=	36° 24′ 58″ N
Corr. Lat.	=	36° 57′ 51″ N
Error	=	32′ 53″

In this case, the latitude is nearly 33 miles in error, which shows the absurdity and danger of using such a constant for all kinds of altitudes, particularly when navigating near or approaching a coast at night or in misty weather.

EXAMPLES FOR PRACTICE

1. On June 23, 1899, in longitude 165° 45′ W, the observed meridian altitude of the sun's lower limb was 65° 14′ 20″, the observer facing south. Index error = − 6′ 25″. Height of eye = 14 feet. Find the latitude. Ans. Lat. = 48° 6′ 26″ N

2. On August 2, 1899, in longitude 159° 30′ E, the observed meridian altitude of the sun's upper limb was 46° 14′ 50″, the observer facing north. Index error = − 7′ 15″. Height of eye = 31 feet. Required, the latitude. Ans. Lat. = 26° 21′ 35″ S

3. On July 1, 1899, in longitude 15° 45′ E, the observed meridian altitude of the sun's upper limb (taken in an artificial horizon) was 38° 50′, the observer facing north. Index error = + 2′ 16″. Height of eye = 15 feet. Find the latitude. Ans. Lat. = 47° 44′ 49″ S

4. On February 26, 1900, in longitude 55° 45′ W, the observed meridian altitude of the sun's lower limb was 35° 10.5′, the observer facing south. Index error = − 4′ 50″. Height of eye = 18 feet. Semi-diameter = 16′ 10″. Declination = S 8° 46′ 14.1″. Change in 1^h = 56″. Find the latitude. Ans. Lat. = 46° 0′ 45″ N

5. On September 23, 1899, in longitude 90° 15′ E, the observed meridian altitude of the sun's lower limb was 52° 40′ 55″, the observer facing north. Index error = + 8′ 40″. Height of eye = 9 feet. Find the latitude. Ans. Lat. = 36° 57.4′ S

6. On August 15, 1900, in longitude 30° 50′ W, the observed meridian altitude of the sun's lower limb was 75° 57′ 20″, the observer facing north. Index error = − 7′ 35″. Height of eye = 21 feet. Semi-diameter = 15′ 49″. Declination = N 14° 7′ 44″. Change in 1^h = 46.7″. Required, the latitude. Ans. Lat. = 0° 7′ 1″ N

LATITUDE BY A MERIDIAN ALTITUDE OF A STAR

11. Directions.—Find what bright stars will be on the meridian at the time the observation is to be made, according to instructions given in *Nautical Astronomy*, Part 2. Select one or more of these stars, giving preference to those of high declination, because their movements in altitude are very slow when near the meridian. Find and note the exact mean or apparent time when the selected star or stars will be on your meridian, as explained in *Nautical Astronomy*, Part 2. Then be ready with the sextant, and commence a

few minutes before the specified time to measure the altitude, the same as in the case of the sun. Be sure that the star selected is identified without doubt, remembering that it will be to the *south* of you if you are in north latitude and the declination of the star is south, or when its declination is north and less than your latitude, but that it will be to the *north* of you if its declination and your latitude are both north, the former being greater than the latter. It is evident that the same principle applies also to the southern hemisphere. Having measured the altitude, correct it for index error, dip, and refraction, thus obtaining the true meridian altitude and, hence, the zenith distance; this, when applied to the star's declination according to the rule of Art. 4, will give the required latitude.

In the following examples, the declination should be taken from the abridgment of the Nautical Almanac accompanying *Nautical Astronomy*, Part 2.

EXAMPLE 1.—On October 19, 1899, the observed meridian altitude of the star Sirius (α Canis Majoris) was 45° 30′ 30″, the observer facing south. Index error = + 1′ 30″. Height of eye = 23 feet. Find the latitude.

SOLUTION.—			
Obs. Mer. Alt. ✳	=	45° 30′ 30″	
I. E.	=	+ 1′ 30″	
		45° 32′ 0″	
Dip	=	− 4′ 42″	
		45° 27′ 18″	
Ref.	=	− 0′ 56″	
True Alt.	=	45° 26′ 22″	
		90° 0′ 0″	
Z. D.	=	44° 33′ 38″ N	
✳ Decl.	=	16° 34′ 39″ S	
Lat. required	=	27° 58′ 59″ N.	Ans.

The star's declination is taken directly from the catalog of Fixed Stars in the Nautical Almanac, and applied without any corrections whatever.

EXAMPLE 2.—On January 5, 1899, the observed meridian altitude of the star Rigel (β Orionis) was 84° 54′ 20″, the observer facing north. Index error = + 1′ 10″. Height of eye = 21 feet. Required, the latitude.

SOLUTION.— Obs. Mer. Alt. ✳ =	84° 54′ 20″
I. E. =	+ 1′ 10″
	84° 55′ 30″
Dip =	− 4′ 29″
	84° 51′ 1″
Ref. =	− 0′ 6″
True Alt. =	84° 50′ 55″
	90° 0′ 0″
Z. D. =	5° 9′ 5″ S
✳ Decl. =	8° 19′ 6″ S
Lat. required =	13° 28′ 11″ S. Ans.

EXAMPLE 3.—On February 2, 1899, the meridian altitude of the star Regulus (*α* Leonis), as observed in an artificial horizon, was 114° 20′ 30″, the observer facing south. Index error = − 5′ 16″. Find the latitude.

SOLUTION.— Obs. double Mer. Alt. ✳ =	114° 20′ 30″
I. E. =	− 5′ 16″
	2)114° 15′ 14″
Obs. Mer. Alt. ✳ =	57° 7′ 37″
Ref. =	− 0′ 37″
True Alt. =	57° 7′ 0″
	90° 0′ 0″
Z. D. =	32° 53′ N
✳ Decl. =	12° 27.6′ N
Lat. required =	45° 20.6′ N. Ans.

12. Visibility of Stars.—It is well to bear in mind that if the declination of a star and the latitude of the observer are of different names, one being north and the other south, and if the declination is greater than the complement of the latitude, such star (or stars) is never above the horizon of the observer. For instance, if the declination of a certain star S, Fig. 4, is 65° S and the observer's latitude at o is 50° N, it is evident that the star S will not rise above the horizon HH' because its declination ES is greater than the complement $ZP(=EH)$ of the latitude. Had the star been situated at S_1, its declination ES_1 being south and less than EH, the complement of the latitude, then it would have risen above the horizon of the observer at o, at an altitude equal to the arc HS_1. Therefore, when the

declination of a star and the latitude of a place are known, it is a comparatively easy matter to find whether that star will rise above the horizon of that place or not.

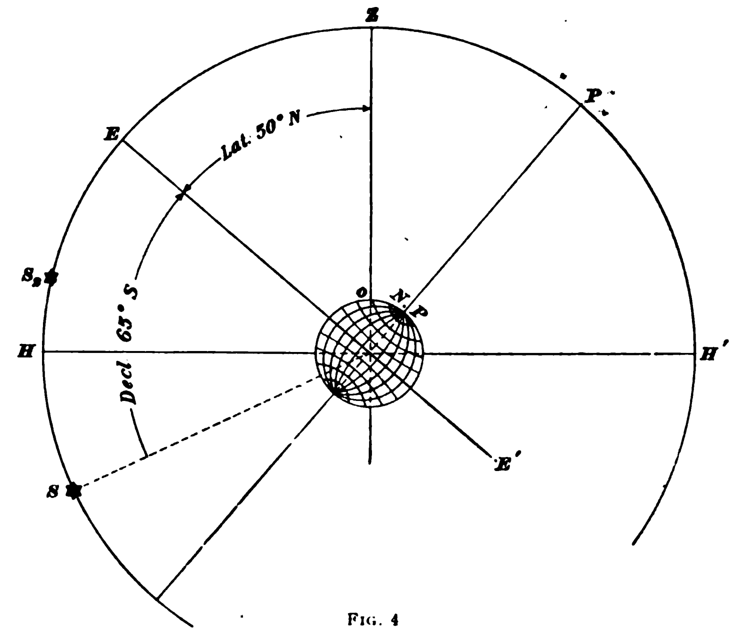


FIG. 4

ILLUSTRATION.—Name some bright stars that do not rise above the horizon of New York City (latitude 40° N).

ANSWER.—The colatitude of New York is 90° − 40 = 50°. Hence, all stars whose declinations are south and greater than 50° will not be visible in New York. Looking over the catalog of Fixed Stars, the following stars of the first magnitude are found to be in this class:

α Eridani (*Achernar*)
α Crucis
β Centauri
α Centauri

13. To Calculate the Approximate Altitude in Advance.—At sea it may sometimes be very desirable to know in advance the approximate meridian altitude of the body to be observed, so as to render the observation simple and to facilitate the identification of the star. This is accomplished in the following manner:

Let S, S_1, and S_2, Fig. 5, represent the different positions of a star, or other celestial body, on the meridian. Then, when the star is at S,

$$\text{the altitude } SH = 90° - (EZ + ES),$$

or altitude = 90° − [latitude (N) + declination (S)] **(1)**

When the star is at S_1,

$$\text{the altitude } S_1H = 90° - (EZ - ES_1),$$

or altitude = 90° − [latitude (N) − declination (N)] **(2)**

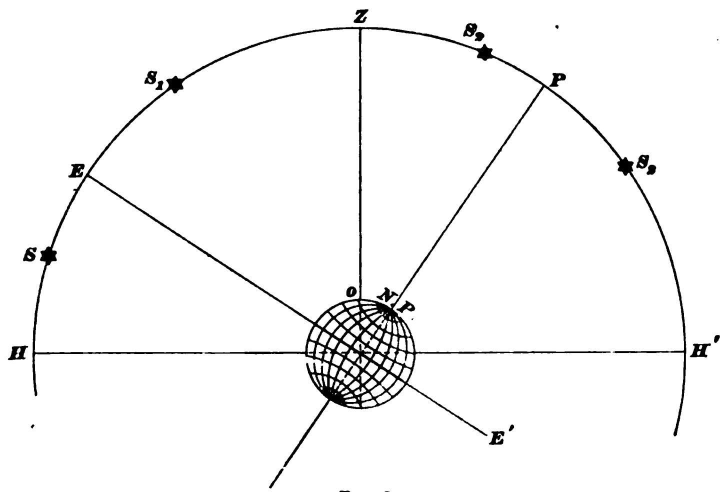


Fig. 5

When the star is situated at S_2,

$$\text{the altitude } S_2H' = 90° - (ES_2 - EZ),$$

or altitude = 90° − [declination (N) − latitude (N)] **(3)**

When the star is situated at S_3, or below the pole,

$$\text{the altitude } S_3H' = PH' - PS_3,$$

or altitude = latitude − polar distance **(4)**

In the cases just illustrated the latitude of the observer at *o* is north. Similar results (with names reversed) will be obtained if the latitude is south.

14. By paying especial attention to the names of each quantity in the preceding formulas, it is evident that the zenith distance of a celestial body, when on the meridian, is

equal to the *difference* of the latitude and declination when they are of the *same name*, but equal to their *sum* when they are of *different names*. The zenith distance subtracted from 90° gives the required meridian altitude.

EXAMPLE 1.—Assume the latitude in, by dead reckoning, to be 25° 30′ N, and the declination of the star to be 52° 20′ N. What will be the approximate altitude of that star at the time of its meridian passage?

SOLUTION.—Since both quantities have the same name, the difference is taken. Thus,

$$\begin{aligned} \text{Alt.} &= 90° - (\text{Decl.} - \text{Lat.}) \\ &= 90° - (52° 20' - 25° 30') \\ &= 90° - 26° 50' = 63° 10'. \quad \text{Ans.} \end{aligned}$$

EXAMPLE 2.—The latitude in, by dead reckoning, is 10° 15′ N, and the declination of the star to be observed is 25° 40′ S. Find the star's approximate meridian altitude.

SOLUTION.—The quantities being of different names, their sum is taken. Thus,

$$\begin{aligned} \text{Alt.} &= 90° - (\text{Lat.} + \text{Decl.}) \\ &= 90° - (10° 15' + 25° 40') \\ &= 90° - 35° 55' = 54° 5'. \quad \text{Ans.} \end{aligned}$$

15. The altitude thus found is, of course, the approximate true altitude, and in order to find the altitude at which the sextant should be set, the corrections for refraction, dip, and index error must be applied with *reversed* signs. The sextant should then be set at that angle, and, when near the time of the star's meridian passage, the horizon on each side of the north or the south point, as the case may be, is carefully scanned. As soon as the star is identified, its correct altitude is measured in the usual way.

16. In this manner, the meridian altitude of a planet or a star of the first magnitude invisible to the naked eye, can often be observed in daytime by means of a good telescope attached to the sextant. By setting the sextant at an angle equal to the calculated approximate meridian altitude and searching the horizon by means of the telescope near the north or south points a few minutes before the calculated time of transit, the planet may be found without much trouble.

EXAMPLES FOR PRACTICE

1. On January 4, 1899, the observed meridian altitude of the star Markab (α Pegasi) was 30° 59′ 10″, the observer facing north. Index error = + 4′ 2″. Height of eye = 33 feet. Find the latitude.
Ans. Lat. = 44° 24.3′ S

2. On February 3, 1899, the observed meridian altitude of the star Aldebaran (α Tauri) was 56° 23′, the observer facing south. Index error = + 1′ 19″. Height of eye = 28 feet. Required, the latitude.
Ans. Lat. = 49° 59′ 52″ N

3. On January 2, 1899, the observed meridian altitude of the star Sirius (α Canis Majoris) was 53° 23′ 40″, the observer facing south. Index error = + 5′ 0″. Height of eye = 17 feet. Find the latitude.
Ans. Lat. = 20° 1′ 25″ N

4. On March 7, 1899, the observed meridian altitude of the star Arcturus (α Bootis) was 47° 24′ 30″, the observer facing south. Index error = − 2′ 10″. Height of eye = 17 feet. Required, the latitude.
Ans. Lat. = 62° 25.1′ N

5. On January 22, 1899, the latitude in, by dead reckoning, was 40° 46′ N. Find the approximate altitude of the star Algenib (γ Pegasi) at the time of its meridian passage.
Ans. Alt. = 63° 51′

6. On February 1, 1889, the meridian altitude of the star Markab (α Pegasi), as observed in an artificial horizon, was 111° 57′ 10″, the observer facing north. Index error = + 8′ 6″. Required, the latitude.
Ans. Lat. 19° 18.3′ S

LATITUDE BY A MERIDIAN ALTITUDE OF A PLANET

17. Directions.—Find the local mean time of the planet's meridian passage according to the instructions given in *Nautical Astronomy*, Part 2, and from this the corresponding Greenwich date. At the time when the planet is on the meridian, measure the altitude as usual, commencing a few minutes ahead. Bring the center of the planet into contact with the horizon. Correct the altitude for index error, dip, and refraction, and if great accuracy is required, also for semi-diameter (if upper or lower limb is observed) and parallax. Correct the planet's declination according to methods explained in *Nautical Astronomy*, Part 2, and apply same to the zenith distance according to the rule of Art. 4. The result will be the required latitude.

EXAMPLE 1.—On April 1, 1899, at a ship in longitude 140° E, the observed meridian altitude of Jupiter's center was 44° 15′ 40″, the observer facing south. Index error = – 1′ 30″. Height of eye = 30 feet. Find the latitude.

SOLUTION.—

G. M. T. Mer. passage, Mar. 31 = $13^h\,48.6^m$ Change in 24^h = 4.3^m
Corr. = $\frac{140}{360} \times 4.3 = +$ 1.6^m

L. M. T. of passage = $13^h\,50.2^m$, or Apr. 1 at $1^h\,50.2^m$ A. M.
Long. (E) in time = – $9^h\,20^m$

G. D., Apr. 1 = $4^h\,30.2^m$

Decl. of Jupiter, Apr. 1 = S 12° 53′ 46.1″ Change in 1^h = 5.11″
Corr. for 4.5^h = – 22.9″ $\times 4.5^h$

Corr. Decl. = S 12° 53′ 23.2″ Corr. = 22.995″

Jupiter's Obs. Mer. Alt. = 44° 15′ 40″
I. E. = – 1′ 30″

44° 14′ 10″
Dip = – 5′ 22″

44° 8′ 48″
Ref. = – 0′ 59″

True Alt. = 44° 7′ 49″
90° 0′ 0″

Z. D. = 45° 52′ 11″ N
Decl. = 12° 53′ 23″ S

Lat. required = 32° 58′ 48″ N. Ans.

EXAMPLE 2.—On March 19, 1899, at a ship in longitude 148° 15′ W, the observed meridian altitude of Jupiter's center was 52° 38′ 20″, the observer facing north. Index error = + 3′ 52″. Height of eye = 27 feet. Required, the latitude.

SOLUTION.—

G. M. T. Mer. passage, Mar. 18 = $14^h\,44^m$ Change in 24^h = 4.2^m
Corr. = $\frac{148}{360} \times 4.2 = -$ 1.7^m

L. M. T. of passage = $14^h\,42.3^m$, or Mar. 19 at $2^h\,42.3^m$ A. M.
Long. (W) in time = + $9^h\,53^m$

G. D., Mar. 19 = $0^h\,35.3^m$

Decl. of Jupiter, Mar. 19 = S 13° 16′ 51″ Change in 1^h = 4″
Corr. for 35^m = – 2″

Corr. decl. = S 13° 16′ 49″

Jupiter's Obs. Mer. Alt.	=	52° 38′ 20″
I. E.	=	+ 3′ 52″
		52° 42′ 12″
Dip	=	− 5′ 5″
		52° 37′ 7″
Ref.	=	− 0′ 43″
True Alt.	=	52° 36′ 24″
		90° 0′ 0″
Z. D.	=	37° 23′ 36″ S
Decl.	=	13° 16′ 49″ S
Lat. required	=	50° 40′ 25″ S. Ans.

EXAMPLES FOR PRACTICE

1. On January 29, 1899, the observed meridian altitude of Venus's center was 35° 54′ 40″, the observer facing south. Index error = + 3′ 42″. Height of eye = 24 feet. Longitude = 150° E. Required, the latitude. Ans. Lat. = 35° 6.6′ N

2. On May 4, 1899, at 11ʰ 19ᵐ P. M., mean time, in longitude 42° 10′ W, the observed meridian altitude of Jupiter's center was 16° 56′, the observer facing south. Index error = − 2′ 8″. Height of eye = 20 feet. Required, the latitude. Ans. Lat. = 61° 39.8′ N

LATITUDE BY A MERIDIAN ALTITUDE OF THE MOON

18. Directions.—Find the local mean time of the moon's meridian passage, and from this the corresponding Greenwich date. Also, for the Greenwich date thus found, take out and correct the moon's semi-diameter, declination, and parallax. This is done according to the instructions given in *Nautical Astronomy*, Part 2. Be ready with the sextant a few minutes before the calculated time of transit, and measure the altitude at the proper time. To the altitude found apply the various corrections, whence the zenith distance applied to the declination, according to the rule of Art. **4**, will produce the required latitude.

EXAMPLE 1.—On August 19, 1899, in longitude 70° 42′ W, the observed meridian altitude of the moon's lower limb was 33° 32′ 20″,

the observer facing south. Index error = − 2′ 15″. Height of eye = 12 feet. Find the latitude.

SOLUTION.—According to directions, the Greenwich date corresponding to the time of the meridian passage is found first. Thus,

☽ Mer. passage, Aug. 19 =	$10^h\ 49.2^m$	Change in 1^h =	2.41^m
Corr. for Long. (W) =	+ 11.3^m		$\times 4.7^h$
L. M. T. of passage, Aug. 19 =	$11^h\ 0.5^m$ P. M.	Corr. =	11.327^m
Long. (W) in time =	+ $4^h\ 42.8^m$		
G. D., Aug. 19 =	$15^h\ 43.3^m$		

The requisite elements of the moon are then taken from the Nautical Almanac and properly corrected. Thus,

☽ S. D. (midnight) =	16′ 43.4″	Change in 12^h =	1.8″
Corr. for 3.7^h =	+ 0.5″		$\times 3.7^h$
☽ Hor. S. D. =	16′ 43.9″		12)6.66″
Corr. for Alt. =	+ 10″ (N. T., page 167)	Corr. =	0.55″
☽ Corr. S. D. =	16′ 53.9″		
☽ H. P. (midnight) =	61′ 16.2″	Change in 1^h =	0.74″
Corr. for 3.7^h =	+ 2.7″		$\times 3.7^h$
☽ Corr. H. P. =	61′ 18.9″	Corr. =	2.738″
☽ Decl. =	S 13° 57′ 55″	Change in 1^m =	12.66″
Corr. for 43.3^m =	− 9′ 8″		$\times 43.3^m$
☽ Corr. Decl. =	S 13° 48′ 47″	Corr. =	548.178″
		Or =	9′ 8″

The observed meridian altitude is now reduced to true by the application of usual corrections, whence the required latitude is found according to the rule of Art. **4**. Thus,

Obs. Mer. Alt. ☽ =	33° 32′ 20″
I. E. =	− 2′ 15″
	33° 30′ 5″
Dip =	− 3′ 24″
App. Alt. ☽ =	33° 26′ 41″
☽ S. D. =	+ 16′ 54″
App. Alt. ☽ =	33° 43′ 35″
Corr. for Par. and Ref. =	+ 49′ 34″ (N. T., page 170)
True Mer. Alt. =	34° 33′ 9″
	90° 0′ 0″
Z. D. =	55° 26′ 51″ N
☽ Decl. =	13° 48′ 47″ S
Lat. required =	41° 38′ 4″ N. Ans.

EXAMPLE 2.—On July 20, 1899, in longitude 126° 5′ W, the observed meridian altitude of the moon's lower limb was 42° 18′ 34″, the observer facing south. Index error = + 4′ 16″. Height of eye = 16 feet. Required, the latitude.

SOLUTION.—Proceed as in the foregoing example. Thus,

☽ Mer. passage, July 20	= $10^h\ 6.8^m$	Change in 1^h	= 2.6^m
Corr. for Long. (W)	= + 21.8^m		× 8.4^h
L. M. T. of passage	= $10^h\ 28.6^m$ P. M.	Corr.	= 21.84^m
Long. (W) in time	= $8^h\ 24.3^m$		
G. D., July 20	= $18^h\ 52.9^m$		

☽ S. D. (midnight)	= 16′ 28.4″	Change in 12^h	= 5.4″
Corr. for 6.9^h	= + 3.1″		× 6.9^h
☽ Hor. S. D.	= 16′ 31.5″		12)37.26″
Corr. for Alt.	= + 11.9″ (N. T., page 167)	Corr.	= 3.1″
☽ Corr. S. D.	= 16′ 43.4″		

☽ H. P. (midnight)	= 60′ 20.9″	Change in 1^h	= 1.8″
Corr. for 6.9^h	= + 12.4″		× 6.9^h
☽ Corr. H. P.	= 60′ 33.3″	Corr.	= 12.42″

☽ Decl.	= S. 22° 50′ 18.3″	Change in 1^m	= 4.74
Corr. for 52.9^m	= − 4′ 10.7″		× 52.9^m
☽ Corr. Decl.	= S 22° 46′ 7.6″		60)250.746″
		Corr.	= 4′ 10.7″

Obs. Mer. Alt. ☽	= 42° 18′ 34″
I. E.	= + 4′ 16″
	42° 22′ 50″
Dip	= − 3′ 55″
App. Alt. ☽	= 42° 18′ 55″
☽ S. D.	= + 16′ 43″
App. Alt. ☽	= 42° 35′ 38″
Corr. for Par. and Ref.	= + 43′ 32″ (N. T., page 171)
True Mer. Alt.	= 43° 19′ 10″ N
	90° 0′ 0″
Z. D.	= 46° 40′ 50″ N
☽ Decl.	= 22° 46′ 7″ S
Lat. required	= 23° 54′ 43″ N. Ans.

EXAMPLE 3.—On July 23, 1899, in the forenoon, when in longitude 15° 45′ E, the observed meridian altitude of the moon's upper limb

was 73° 26′ 5″, the observer facing north. Index error = − 1′ 20″. Height of eye = 10 feet. Required, the latitude.

SOLUTION.—

☽ Mer. passage, July 22	= 12ʰ 9.8ᵐ	Change in 1ʰ = 2.47ᵐ
Corr. for Long. (E)	= − 2.5ᵐ	
L. M. T. of passage	= 12ʰ 7.3ᵐ, or July 23 at 0ʰ 7.3ᵐ A. M.	
Long. (E) in time	= −1ʰ 3ᵐ	
G. D., July 22	= 11ʰ 4.3ᵐ	
☽ S. D. (midnight)	= 16′ 43.4″ (By inspection)	
Corr. for Alt.	= + 17.6″ (N. T., page 167)	
☽ Corr. S. D.	= 17′ 1″	
☽ H. P. (midnight)	= 61′ 16″ (By inspection)	
☽ Decl.	= S 17° 22′ 10.9″	Change in 1ᵐ = 10.9″
Corr. for 4.3ᵐ	= − 46.9″	× 4.3ᵐ
☽ Corr. Decl.	= S 17° 21′ 24″	Corr. = 46.87″
Obs. Mer. Alt. ☽̲	= 73° 26′ 5″	
I. E.	= − 1′ 20″	
	73° 24′ 45″	
Dip	= − 3′ 5″	
App. Alt. ☽̲	= 73° 21′ 40″	
☽ S. D.	= − 17′ 1″	
App. Alt. ☽	= 73° 4′ 39″	
Corr. for Par. and Ref.	= + 17′ 33″ (N. T., page 174)	
True Mer. Alt.	= 73° 22′ 12″	
	90° 0′ 0″	
Z. D.	= 16° 37′ 48″ S	
☽ Decl.	= 17° 21′ 24″ S	
Lat. required	= 33° 59′ 12″ S. Ans.	

19. Cautionary Remarks.—In making observations of the moon for the purpose of determining the latitude, the following should be borne in mind: When the moon is near the equator and its declination is changing rapidly, the maximum, or greatest, altitude may differ considerably (not more than 2′ or 3′ in extreme cases) from the meridian altitude measured at the moment of the calculated meridian passage. Similarly, when the ship is steaming at a high speed on courses near north or south, true, the same thing may occur.

In such cases, the altitude measured at the calculated time of the meridian passage should be considered as the observed meridian altitude.

20. When observing the moon in partly clouded weather, the dark shadow that is usually projected on the water vertically below the moon often renders the sea horizon uncertain and not clearly defined. The navigator should not place too much confidence in the accuracy of observations taken under such circumstances. Again, when observing the moon in clear weather, the upper edge of the illuminated part of the sea horizon should be brought in contact with the moon's limb.

EXAMPLES FOR PRACTICE

1. On October 18, 1899, in longitude 126° 35′ W, the observed meridian altitude of the moon's lower limb was 67° 8′ 55″, the observer facing south. Index error = − 4′ 25″. Height of eye = 16 feet. Find the latitude. Ans. Lat. = 38° 0.8′ N

2. On March 19, 1899, in longitude 145° 42′ E, the meridian altitude of the moon's lower limb, as observed in an artificial horizon, was 65° 1′ 20″, the artificial horizon being to the north of the observer. Index error = − 1′ 40″. Find the latitude. Ans. Lat. = 32° 43.9′ S

3. On November 24, 1899, the observed meridian altitude of the moon's lower limb was 44° 57′ 30″, the observer facing south. At the instant of observation, the ship's chronometer indicated 17^h 54.7^m correct Greenwich mean time. The ship was on the meridian of Greenwich. Index error = + 4′ 15″. Height of eye = 18 feet. Find the latitude. Ans. Lat. = 50° 5.2′ N

LATITUDE BY A MERIDIAN ALTITUDE BELOW THE POLE

21. Explanation.—Opportunities often present themselves when an observer is able to measure the meridian altitude of a celestial body at its transit below the pole. The latitude derived from such an observation is quite as reliable as that derived from a similar altitude above the pole. As has been stated, any celestial body whose polar distance is less than the observer's latitude is circumpolar and, consequently, may be observed at its lower meridian

passage. However, on account of the varying and uncertain condition of the atmosphere near the horizon, the refraction for altitude below 6° or 7° cannot be estimated with accuracy. For this reason, very low altitudes should be avoided.

Since the maximum value of the sun's declination is about $23\frac{1}{2}°$, and therefore its polar distance is never much less than 67°, it follows that in order to measure a meridian altitude of that body below the pole, the observer's latitude should not be less than 67° + 7°, or 74°. In latitudes below 74° N and 74° S, therefore, the sun cannot be used for meridian altitudes below the pole. Hence, meridian observations at the lower transit of the sun are restricted to high latitudes only, and therefore are not generally available to the common routes of commercial navigation.

Stars, on the other hand, can be used for observation when below the pole in nearly all latitudes above 10° and 15°. Among them, the pole star is frequently selected for finding the latitude at sea in the northern hemisphere, as it is always above the horizon both at its upper and lower transit, and on cloudless nights is always of sufficient brightness to be readily recognized.

22. Measuring the Altitude at Lower Transit. When measuring a meridian altitude below the pole, it is evident that the observed object will descend continually until the meridian is reached, when it will stop and begin to ascend. The lowest altitude measured is therefore the required meridian altitude.

23. Directions.—Find the time of the lower meridian passage according to the instructions given in *Nautical Astronomy*, Part 2, or note the chronometer at the instant of measuring the altitudes. If the observed body is a star, the Greenwich date is not necessary, since the change of declination of a star in 12 hours is inappreciable, and will be the same as that given in the Nautical Almanac. If the sun, the moon, or a planet is observed, the Greenwich date must be known and the respective elements corrected accordingly. The declination being found, subtract it from 90°; the result

is the polar distance, which, when added to the true meridian altitude, will produce the required latitude.

Example 1.—On February 16, 1899, the observed meridian altitude of the star Canopus (α Argus) at its lower meridian passage was 29° 8″ 10″. Index error = + 2′ 20″. Height of eye = 22 feet. Find the latitude.

Solution.—Obs. Mer. Alt. ✳ =	29° 8′ 10″
I. E. =	+ 2′ 20″
	29° 10′ 30″
Dip =	− 4′ 36″
	29° 5′ 54″
Ref. =	− 1′ 42″
True Mer. Alt. =	29° 4′ 12″
✳ Decl. =	52° 38′ 25″ S
	90° 0′ 0″
P. D. =	37° 21′ 35″
True Alt. =	29° 4′ 12″
Lat. required =	66° 25′ 47″ S. Ans.

Example 2.—On January 7, 1899, the observed altitude of Polaris when on the meridian below the pole was 41° 36′. Index error = − 4′ 10″. Height of eye = 17 feet. Required, the latitude.

Solution.—Obs. Mer. Alt. ✳ =	41° 36′ 00″
I. E. =	− 4′ 10″
	41° 31′ 50″
Dip =	− 4′ 2″
	41° 27′ 48″
Ref. =	− 1′ 5″
True Mer. Alt. =	41° 26′ 43″
✳ Decl. =	88° 46′ 8″ N
	90° 0′ 0″
P. D. =	1° 13′ 52″
True Alt. =	41° 26′ 43″
Lat. required =	42° 40′ 35″ N. Ans.

The latitude resulting from the observed meridian altitude of a celestial object below the pole is necessarily of the same name as the declination, because only stars having north declination can be seen below the pole in north latitude, and, likewise, only those having south declination can be seen in south latitude.

24. To obtain an approximate altitude of the star to be observed at its lower meridian passage, subtract the star's polar distance from the latitude in by dead reckoning; the remainder, when corrected for index error, dip, and refraction, *reversed*, will be the required altitude to which the sextant should be set for observation.

EXAMPLES FOR PRACTICE

1. On January 15, 1899, the observed meridian altitude of the star α Ursæ Majoris at its lower transit was 14° 7′ 10″. Index error = + 3′ 15″. Height of eye = 20 feet. Required, the latitude.
Ans. Lat. = 41° 44.5′ N

2. On February 2, 1899, the observed meridian altitude (lower passage) of the star α Crucis was 17° 32′ 10″. Index error = − 2′ 25″. Height of eye = 26 feet. Find the latitude. Ans. Lat. = 44° 49.5′ S

LATITUDE BY REDUCTION TO THE MERIDIAN

FIRST METHOD

25. Explanation.—When about to measure the meridian altitude at apparent noon, it may sometimes happen that the desired altitude is lost on account of the sun being obscured by clouds at the time of its maximum altitude, but that a few minutes before or after 12 o'clock the sky is clear and the sun available for observations. In such cases, the latitude may be found by measuring the altitude a few minutes before or after apparent noon, and reducing it to what it would have been had it been measured at noon, when the sun was on the meridian. This reduction of the measured altitude to meridian altitude is based on the fact that, when very near noon, the altitude varies as the square of the interval of time from noon. The square of this interval, when multiplied by the change in 1 minute from apparent noon, will accordingly give a correction to be applied to the observed altitude, from which is obtained the true meridian altitude, and, thence, the required latitude in the usual way.

26. Referring to Fig. 6, where P is the pole, and S and S_1 the position of the sun before and after crossing the meridian $m\,n$, it is evident that the interval of time referred to is the hour angle of the sun at the instant of measuring the altitude. If observed before noon, or when the sun is at S, it is the easterly hour angle; if observed after noon, or at S_1, it is the westerly hour angle. To find this hour angle when at S, the local apparent time is subtracted from 24 hours, while at S_1 the hour angle is equal to the local apparent time. Therefore, to compute the latitude from an altitude taken near the meridian, the ship's longitude as well as the Greenwich mean time at the moment of observation must be known. When these elements are known, the local apparent time is found by applying the equation of time to the local mean time, whence the required interval of time is readily determined. To facilitate the calculations involved and render the whole operation as simple as possible, use should be made of the tables found on pages 159 to 163 of the Nautical Tables. The first of these tables gives the change of altitude in 1 minute from noon, and the latter, that found on page 163, gives the square of the interval up to 13 minutes. When using the table of Variation of Altitude in 1^m From Noon, attention should be given to whether the declination of the observed body is of the same or of a different name from the latitude of the ship, and the table must be entered accordingly.

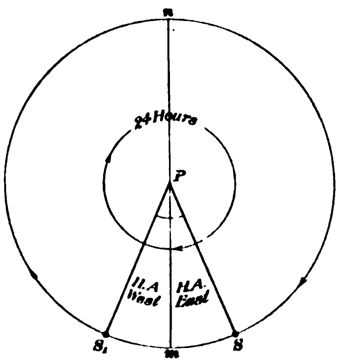


Fig. 6

Since the table of the squares of interval is carried only up to 13 minutes, the interval of time on either side of the meridian $m\,n$, Fig. 6, should not exceed 13 minutes; in other words, to utilize this method, altitudes must be taken within 13 minutes of apparent noon. Another stipulation is that the declination and latitude in, by dead reckoning, must differ by at least 4°.

27. From the preceding remarks, the following rule may be formulated:

Rule.—*At the instant of measuring the altitude, note the time indicated by the chronometer (either directly by an assistant or by a watch previously compared with the chronometer). For the Greenwich mean time thus found, take out from the Nautical Almanac the necessary elements, such as declination, equation of time, etc. Reduce the observed altitude to true by applying the proper corrections. To the Greenwich mean time apply the longitude in time, and to the local mean time thus found apply the equation of time, whence the local apparent time is obtained. If the local apparent time is less than 24 hours, subtract it from 24^h; if greater than 24 hours, subtract 24^h from it; the remainder is the hour angle. With the declination and latitude in, by dead reckoning, take from the table headed Variation of Altitude, the corresponding change of altitude for 1^m; with minutes and seconds of the hour angle, take from the table headed Squares of Interval, the corresponding value. Multiply the two numbers thus found, and add the product (reduced to minutes and seconds) to the true altitude. The result is the true meridian altitude, from which the latitude is found by the rule of Art.* **4.**

EXAMPLE 1.—On July 11, 1899, in longitude 40° W, an altitude of the sun's lower limb taken near the meridian was 61° 40′ 10″, the observer facing south. Index error = + 1′ 20″. Height of eye = 15 feet. Latitude in, by dead reckoning = 50° N. Chronometer at instant of observation = $2^h\,40^m\,40^s$, its error on Greenwich mean time being $2^m\,40^s$ fast. Find the latitude.

SOLUTION.—Proceed according to the foregoing rule. Thus,

Chron.	=	$2^h\,40^m\,40^s$
Error (fast)	=	$-\quad 2^m\,40^s$
G. D., July 11	=	$2^h\,38^m\;\;0^s$
Long. (W) in time	=	$2^h\,40^m\;\;0^s$
L. M. T., July 10	=	$23^h\,58^m\;\;0^s$
Corr. Eq. of T.	=	$-\quad 5^m\,14.9^s$
L. App. T., July 10	=	$23^h\,52^m\,45^s$
Subtract from		$24^h\;\;0^m\;\;0^s$
Interval from App. noon, July 11	=	$7^m\,15^s$ = H. A. easterly

⊙ Decl.	= N 22° 6′ 56.4″	Change in 1^h =	19.9″
Corr. for 2.6^h	= − 51.7″		× 2.6^h
Corr. Decl.	= N 22° 6′ 4.7″	Corr. =	51.74″
Eq. of T.	= 5^m 14.07^s	Change in 1^h =	0.34^s
Corr. for 2.6^h	= + 0.88^s		× 2.6^h
Corr. Eq. of T.	= 5^m 14.9^s (−)	Corr. =	0.884^s

With the latitude in, by dead reckoning, and the declination of the sun, find from the table, page 162, Nautical Tables, the corresponding number; likewise, find the number in the table on page 163 corresponding to the hour angle or interval in time from apparent noon. The numbers referred to are as follows:

The first table gives 2.5″
The second table gives × 52.6″

Product = 60)131.50″
Corr. = 2′ 11.5″ (Additive to true altitude)

Obs. Alt. ☉	= 61° 40′ 10″
I. E.	= + 1′ 20″
	61° 41′ 30″
Dip	= − 3′ 48″
	61° 37′ 42″
S. D.	= + 15′ 46″
App. Alt. ⊖	= 61° 53′ 28″
Ref.	= − 0′ 31″
	61° 52′ 57″
⊙ Par.	= + 0′ 4″
True Alt.	= 61° 53′ 1″
Corr.	= + 2′ 11″
True Mer. Alt.	= 61° 55′ 12″
	90° 0′ 0″
Z. D.	= 28° 4′ 48″ N
⊙ Decl.	= 22° 6′ 5″ N
Lat. required	= 50° 10′ 53″ N. Ans.

EXAMPLE 2.—The altitude of the sun's lower limb observed just after transition on October 17, 1899, was 38° 43′ 15″. The observer was facing south, his longitude being 127° 30′ W. Index error = − 2′ 30″. Height of eye = 22 feet. Estimated latitude = 42° N. At the instant of observation, the chronometer indicated 8^h 22^m 5^s, its error on Greenwich mean time being 3^m 12^s slow. What is the correct latitude?

SOLUTION.—According to the preceding rule, the solution is as follows:

Chron.	= $8^h\ 22^m\ 5^s$
Error (slow)	= + $3^m\ 12^s$
G. D., Oct. 17	= $8^h\ 25^m\ 17^s$
Long. (W) in time	= $8^h\ 30^m\ 0^s$
L. M. T., Oct. 16	= $23^h\ 55^m\ 17^s$
Corr. Eq. of T.	= + $14^m\ 39^s$
L. App. T., Oct. 16	= $24^h\ 9^m\ 56^s$
Interval from App. noon, Oct. 17	= $9^m\ 56^s$ = H. A. westerly

⊙ Decl.	= S 9° 16′ 47.2″	Change in 1^h	= 54.9″
Corr. for 8.4^h	= + 7′ 41.2″		× 8.4^h
Corr. Decl.	= S 9° 24′ 28.4″	Corr.	= 461.16″
		Or	= 7′ 41.2″
Eq. of T.	= $14^m\ 34.9^s$	Change in 1^h	= $.5^s$
Corr. for 8.4^h	= + 4.2^s		× 8.4^h
Corr. Eq. of T.	= $14^m\ 39.1^s$(+)	Corr.	= 4.2^s

In this case, the latitude and declination have *different* names; hence, the table on page 159 of the Nautical Tables is entered, and the nearest corresponding number is found to be 1.9. Then, entering the table on page 163, for the square of $9^m\ 56^s$, the required number is found to be 98.7. These numbers are then multiplied. Thus,

Corr. = 1.9 × 98.7 = 187.53″ = 3′ 7.5″ (Additive to true altitude)

Obs. Alt. ☉̲	= 38° 43′ 15″
I. E.	= − 2′ 30″
	38° 40′ 45″
Dip	= − 4′ 36″
	38° 36′ 9″
S. D.	= + 16′ 6″
App. Alt. ⊖	= 38° 52′ 15″
Ref.	= − 1′ 11″
	38° 51′ 4″
⊙ Par.	= + 0′ 7″
True Alt.	= 38° 51′ 11″
Corr.	= + 3′ 7.5″
True Mer. Alt.	= 38° 54′ 18.5″
	90° 0′ 0″
Z. D.	= 51° 5′ 41.5″ N
⊙ Decl.	= 9° 24′ 28.4″ S
Lat. required	= 41° 41′ 13.1″ N. **Ans.**

28. Application of Method to Stars and Planets. This method is applicable also to stars and planets when for some reason the meridian altitude is liable to be lost, provided the interval of time between measuring the altitude and the time of transit is not greater than 13 minutes, and the difference between the declination and the latitude in, by dead reckoning, is at least 4°. The order of procedure in case a star or a planet is observed is substantially the same as for the sun, except that the interval of time is found by comparing the mean time of the star's or planet's transit with the mean time at the instant of measuring the altitude.

EXAMPLE.—On May 31, 1899, in longitude 30° W, an altitude of the star Regulus (α Leonis), observed near the meridian, was 80° 15′ 30″, the observer facing north. Index error = + 3′ 48″. Height of eye = 17 feet. Latitude in, by dead reckoning = 3° 10′ N. Chronometer at instant of observation = $7^h\ 13^m\ 33^s$, its error on Greenwich mean time being $1^m\ 23^s$ slow. Required, the latitude.

SOLUTION.—First find the local mean time at the instant of measuring the altitude. Thus,

Chron.	=	$7^h\ 13^m\ 33^s$
Error (slow)	=	$+\ 1^m\ 23^s$
G. D., May 31	=	$7^h\ 14^m\ 56^s$
Long. (W) in time	=	$-\ 2^h\ 0^m\ 0^s$
L. M. T.	=	$5^h\ 14^m\ 56^s$ (At instant of observation)

Then find the local mean time of the star's transit, or meridian passage. Thus,

R. A. ✳	=	$10^h\ 3^m\ 0^s$
Sid. time G. M. N.	=	$4^h\ 35^m\ 4^s$
Approx. L. M. T.	=	$5^h\ 27^m\ 56^s$
Long. (W) in time	=	$2^h\ 0^m\ 0^s$
Approx. G. M. T. of transit	=	$7^h\ 27^m\ 56^s$
Sid. time G. M. N.	=	$4^h\ 35^m\ 4^s$
Corr. for $7^h\ 28^m$, Table III	=	$1^m\ 13.6^s$ (N. A.)
R. A. M. S.	=	$4^h\ 36^m\ 17.6^s$
R. A. ✳	=	$10^h\ 3^m\ 0^s$
L. M. T. of transit	=	$5^h\ 26^m\ 42.4^s$
L. M. T. at Obs.	=	$5^h\ 14^m\ 56^s$
Interval in mean time	=	$11^m\ 46^s$
Corr. for 11^m, Table III	=	$+\ 2^s$ (N. A.)
Interval in Sid. time	=	$11^m\ 48^s$

Since the observed body is a star, the interval in mean time should be converted into a sidereal interval by Table III, Nautical Almanac, as shown. For the sidereal interval thus found, the latitude in, by dead reckoning, and the declination of the star, the corresponding values are taken from tables previously referred to. Thus,

The first table gives		12.1″
The second table gives		× 139.2″
Corr.	=	1,684.32″
Or	=	28′ 4.3″
Obs. Alt. ✳	=	80° 15′ 30″
I. E.	=	+ 3′ 48″
		80° 19′ 18″
Dip	=	− 4′ 2″
		80° 15′ 16″
Ref.	=	− 0′ 10″
True Alt.	=	80° 15′ 6″
Corr.	=	+ 28′ 4″
True Mer. Alt.	=	80° 43′ 10″
		90° 0′ 0″
Z. D.	=	9° 16′ 50″ S
✳ Decl.	=	12° 27′ 32″ N
Lat. required	=	3° 10′ 42″ N. Ans.

SECOND METHOD

29. Explanation.—In determining the latitude by reduction to the meridian according to the method just described, the interval of time between transit and observation was restricted to 13 minutes. By the method now to be considered, an altitude may be observed to *within an hour of the meridian passage;* in other words, the interval of time, or hour angle, may come near but should not exceed 60 minutes. Thus, the latitude may be computed by noting the time and measuring an altitude of the sun as early as 5 or 10 minutes past 11 o'clock, apparent time, and as late as 50 to 55 minutes past 12 o'clock, or apparent noon. The hour angle of the observed body being found, the latitude is computed from the following formulas:

$$\tan M = \sec \text{hour angle} \times \tan \text{declination} \quad (1)$$

$$\cos N = \sin M \times \sin \text{altitude (true)} \times \operatorname{cosec} \text{declination} \quad (2)$$

$$\text{Latitude} = M \pm N \quad (3)$$

M and N denote, respectively, a quantity the sum or difference of which will produce the required latitude. The quantity M will have the same sign as the declination, north declination being positive (+) and south declination negative (−). The quantity N may be either positive or negative; consequently, two values are derived by formula **3**, but of course only the value that agrees nearest with the latitude in, by dead reckoning, is admissible. To avoid uncertainty, however, N should be marked (+) when the zenith distance of the observed body is north and (−) when the zenith distance is south. The algebraic sum of M and N is the required latitude, (+) indicating north and (−) south latitude.

30. For observation of the sun, the following rule should be applied:

Rule.—*Find the local apparent time, or hour angle, at the instant of measuring the altitude. Convert the minutes and seconds of this hour angle into degrees, minutes, and seconds. Take out the necessary elements from the Nautical Almanac and correct them; then find the quantity M by formula* **1**, *Art.* **29**, *and the quantity N by formula* **2**. *Take their sum or difference, using the value that is nearest the latitude in, by dead reckoning. The result thus obtained is the required latitude.*

EXAMPLE 1.—On June 8, 1899, in longitude 60° 15′ W, the sun being obscured by clouds at noon, causing the meridian altitude to be lost, an altitude of the lower limb, observed at about 12:40 P. M., was found to be 78° 28′ 40″. At the instant of measuring the altitude, the chronometer indicated $4^h\ 46^m\ 25^s$, its error on Greenwich mean time being $1^m\ 55^s$ fast. Index error = + 1′ 20″. Height of eye = 20 feet. Latitude in, by dead reckoning = 28° 10′ N. Required, the latitude.

SOLUTION.—Proceed according to the foregoing rule. Thus,

$$\begin{array}{rcr}
\text{Chron.} & = & 4^h\ 46^m\ 25^s \\
\text{Error (fast)} & = & -\quad 1^m\ 55^s \\
\hline
\text{G. D., June 8} & = & 4^h\ 44^m\ 30^s \\
\text{Long. (W) in time} & = & -\ 4^h\quad 1^m\quad 0^s \\
\hline
\text{L. M. T.} & = & 0^h\ 43^m\ 30^s \\
\text{Eq. of T.} & = & +\quad 1^m\ 11^s \\
\hline
\text{L. App. T.} & = & 0^h\ 44^m\ 41^s \\
\text{Or, hour angle} & = & 11°\ 10'\ 15''
\end{array}$$

$$\begin{array}{rcl|rcl}
\text{Eq. of T.} & = & 1^m\ 13.45^s & \text{Change in } 1^h & = & 0.47^s \\
\text{Corr. for } 4.7^h & = & -\ \ 2.2^s & & & \times\ 4.7^h \\
\hline
\text{Corr. Eq. of T.} & = & 1^m\ 11.2^s & \text{Corr.} & = & 2.209^s
\end{array}$$

$$\begin{array}{rcl|rcl}
\odot\ \text{Decl.} & = & \text{N } 22°\ 51'\ 30'' & \text{Change in } 1^h & = & 13.47'' \\
\text{Corr. for } 4.7^h & = & +\ \ 1'\ \ 3'' & & & \times\ 4.7^h \\
\hline
\text{Corr. Decl.} & = & \text{N } 22°\ 52'\ 33'' & \text{Corr.} & = & 63.309''
\end{array}$$

$$\begin{array}{rcl}
\text{Obs. Alt. } \underline{\odot} & = & 78°\ 28'\ 40'' \\
\text{I. E.} & = & +\ \ 1'\ 20'' \\
\hline
 & & 78°\ 30'\ \ 0'' \\
\text{Dip} & = & -\ \ 4'\ 23'' \\
\hline
 & & 78°\ 25'\ 37'' \\
\odot\ \text{S. D.} & = & +\ 15'\ 47'' \\
\hline
 & & 78°\ 41'\ 24'' \\
\text{Ref. and } \odot\ \text{Par.} & = & -\ \ 0'\ 10'' \\
\hline
\text{True Alt.} & = & 78°\ 41'\ 14''
\end{array}$$

The true altitude being found, calculate the quantity M according to formula **1**, Art. **29**. Thus,

$$\begin{array}{rcl}
\log\sec 11°\ 10'\ 15'' & = & 0.00830 \\
\log\tan 22°\ 52'\ 33'' & = & 9.62522 \\
\hline
\log\tan M & = & 9.63352 \\
M & = & 23°\ 16'
\end{array}$$

Then calculate the quantity N according to formula **2**. Thus,

$$\begin{array}{rcl}
\log\sin 23°\ 16' & = & 9.59661 \\
\log\sin 78°\ 41'\ 14'' & = & 9.99147 \\
\log\operatorname{cosec} 22°\ 52'\ 33'' & = & 10.41036 \\
\hline
\log\cos N & = & 9.99844 \\
N & = & 4°\ 51'
\end{array}$$

Whence, $\text{Lat.} = M + N$

Inserting the value of M and N, respectively, the required latitude is

$$23°\ 16' + 4°\ 51' = 28°\ 7'\ \text{N.}\quad \text{Ans}$$

EXAMPLE 2.—On October 9, 1899, in longitude 140° 45′ E, the observed altitude of the sun's lower limb about 45 minutes before noon was 48° 22′ 10″. Greenwich date at instant of observation was, October 8, $13^h\ 30^m$. Error of chronometer on Greenwich mean time was $6^m\ 58^s$ slow. Height of eye = 17 feet. Index error = + 5′ 8″. Latitude in, by dead reckoning = 46° 18′ S. Find the correct latitude.

SOLUTION.—Proceed according to the foregoing rule. Thus,

Chron., Oct. 8 = $13^h\ 30^m\ 0^s$
Error (slow) = $+\ 6^m\ 58^s$

G. D., Oct. 8 = $13^h\ 36^m\ 58^s$
Long. (E) in time = $9^h\ 23^m\ 0^s$

L. M. T. = $22^h\ 59^m\ 58^s$
Eq. of T. = $+\ 12^m\ 34^s$

L. App. T. = $23^h\ 12^m\ 32^s$
Interval from noon = $47^m\ 28^s$ (Art. **26**)
Or, hour angle = $11°\ 52'$

Eq. of T. = $12^m\ 41^s$ Change in 1^h = $.67^s$
Corr. for 10.4^h = $-\ 7^s$ $\times 10.4^h$

Corr. Eq. of T. = $12^m\ 34^s$ (+) Corr. = 6.968^s

⊙ Decl. = S $6°\ 17'\ 18.5''$ Change in 1^h = $57.1''$
Corr. for 10.4^h = $-\ 9'\ 53.8''$ $\times 10.4^h$

Corr. Decl. = S $6°\ 7'\ 24.7''$ Corr. = $593.84''$

Obs. Alt. ⊙ = $48°\ 22'\ 10''$
I. E. = $+\ 5'\ 8''$

$48°\ 27'\ 18''$
Dip = $-\ 4'\ 2''$

$48°\ 23'\ 16''$
⊙ S. D. = $+\ 16'\ 4''$

$48°\ 39'\ 20''$
Ref. and ⊙ Par. = $-\ 0'\ 44''$

True Alt. = $48°\ 38'\ 36''$

Calculate the quantity M according to formula **1**, Art. **29**. Thus,

log sec $11°\ 52'$ = 10.00938
log tan $6°\ 7'\ 25''$ = 9.03055

log tan M = 9.03993
$M = 6°\ 15'\ 23''$

Then calculate the quantity N according to formula **2**, Art. **29**. Thus,

log sin $6°\ 15'\ 23''$ = 9.03734
log sin $48°\ 38'\ 36''$ = 9.87542
log cosec $6°\ 7'\ 25''$ = 10.97194

log cos N = 9.88470
$N = 39°\ 55'\ 48''$

Whence, Lat. = $M + N$

Or, the required latitude is

$6°\ 15'\ 23'' + 39°\ 55'\ 48'' = 46°\ 11'\ 11''$ S. Ans.

31. Limitation of Method.—The nearer the sun is to the prime vertical, or true east or west, the less accurate will be the result by this method. In fact, when the observed body is on the prime vertical, this method cannot be utilized. Therefore, its use should be confined to within an hour of apparent noon, when its trustworthiness is least affected. The method may, if necessary, be used at longer intervals from noon—to 2 and even 3 hours—but by increasing the interval, the reliability of the method is impaired by several unfavorable conditions. In the naval service, this method is known as the "φ' φ'' *method*," the Greek letters with prime marks being used in place of the M and N in the formulas given here. It should be noted that the method is practically independent of the latitude by account.

32. Application of Method to Stars and Planets. Applying the second method to planets and stars, the rule is practically the same as for the sun, which is evident from the following example:

EXAMPLE.—On January 31, 1899, in longitude 55° 35′ W, an altitude of the star Sirius (α Canis Majoris) measured near the time of transit was 40° 44′ 20″. The declination of the star according to the Nautical Almanac is S 16° 34′ 39″. Chronometer at instant of observation = 12^h 56^m 27^s. Error on Greenwich mean time = 2^m 28^s slow. Latitude in, by dead reckoning = 31° 40′ N. Index error = + 5′ 24″. Height of eye = 25 feet. Find the latitude.

SOLUTION.—First find the local mean time at the instant of observation. Thus,

Chron. =	12^h 56^m 27^s	
Error (slow) =	+ 2^m 28^s	
G. D., Jan. 31 =	12^h 58^m 55^s	
Long. (W) in time =	− 3^h 42^m 20^s	
L. M. T. =	9^h 16^m 35^s	(At observation)

Then find the local mean time of the star's transit, and from this the star's hour angle, or the interval of sidereal time between observation and transit. Thus,

R. A. ✳ (+ 24^h) =	30^h 40^m 42^s
Sid. time G. M. N =	20^h 41^m 57^s
Approx. L. M. T. =	9^h 58^m 45^s
Long. (W) in time =	+ 3^h 42^m 20^s
Approx. G. M. T. of transit =	13^h 41^m 5^s

Sid. time G. M. N.	=	$20^h\ 41^m\ 57^s$	
Corr. for $13^h\ 41^m$, Table III,	=	$2^m\ 14.9^s$	(N. A.)
R. A. M. S.	=	$20^h\ 44^m\ 12^s$	
R. A. ✳	=	$30^h\ 40^m\ 42^s$	
L. M. T. of transit	=	$9^h\ 56^m\ 30^s$	
L. M. T. at Obs.	=	$9^h\ 16^m\ 35^s$	
M. T. interval	=	$39^m\ 55^s$	
Corr., Table III	=	$+\ 6^s$	(N. A.)
Sid. interval	=	$40^m\ 1^s$	
Or, ✳ hour angle	=	$10°\ 0'\ 15''$	
Obs. Alt. ✳	=	$40°\ 44'\ 20''$	
I. E.	=	$+\ 5'\ 24''$	
		$40°\ 49'\ 44''$	
Dip	=	$-\ 4'\ 54''$	
		$40°\ 44'\ 50''$	
Ref.	=	$-\ 1'\ 5''$	
True Alt.	=	$40°\ 43'\ 45''$	

Having found the true altitude and the interval of time between the star's transit and the time at the instant of measuring the altitude, calculate the two quantities M and N. Thus,

$$\tan M \sec \text{H. A.} \times \tan \text{Decl.}$$

$$\begin{aligned}
\log \sec 10°\ 0'\ 15'' &= 0.00665\\
\log \tan 16°\ 34'\ 39'' &= 9.47364\\
\log \tan M &= 9.48029\\
M &= 16°\ 49'
\end{aligned}$$

$$\cos N = \sin M \times \sin \text{Alt.} \times \operatorname{cosec} \text{Decl.}$$

$$\begin{aligned}
\log \sin 16°\ 49' &= 9.46136\\
\log \sin 40°\ 43'\ 45'' &= 9.81455\\
\log \operatorname{cosec} 16°\ 34'\ 39'' &= 10.54468\\
\log \cos N &= 9.82059\\
N &= 48°\ 33'\ 43''\\
\text{Lat.} &= N - M
\end{aligned}$$

Lat. $= 48°\ 33'\ 43'' - 16°\ 49' = 31°\ 44'\ 43''$ N. Ans.

33. Cautionary Remarks.—In dealing with problems of determining the latitude by a star's altitude, reduced to the meridian, an error is frequently committed in finding the local mean time of transit by correcting the right ascension of the mean sun, which is the same as the sidereal time at Greenwich mean noon, for the Greenwich date corresponding

to the instant of observation instead of the Greenwich date corresponding to the time of transit. Thus, in the preceding example, if the sidereal time at Greenwich mean noon had been corrected for $12^h\ 58^m\ 55^s$ instead of for $13^h\ 41^m\ 5^s$, an error of 7^s would have been produced in the right ascension of the mean sun and an error of $3'\ 15''$ in the hour angle. While the corresponding error in the resulting latitude would not have been very great, it should, however, be avoided by a careful computer.

EXAMPLES FOR PRACTICE

1. On June 15, 1899, in the forenoon, an altitude of the sun's lower limb observed near the meridian was $53°\ 13'\ 10''$, the observer facing south. The chronometer at the instant of observation showed $13^h\ 4^m\ 5^s$, its error on Greenwich mean time being $50^m\ 35^s$ fast. Latitude in, by dead reckoning $= 58°\ 50'$ N. Longitude $= 173°\ 56'\ 45''$ E. Index error $= +1'\ 26''$. Height of eye $= 25$ feet. Required, the latitude by first method of reduction to the meridian. Ans. Lat. $= 59°\ 50'$ N

2. On December 31, 1899, in latitude, by dead reckoning, $13°\ 45'$ N and longitude $150°\ 15'$ W, the observed altitude of the sun's lower limb near the meridian was $53°\ 57'$, the observer facing south. Chronometer at instant of observation $= 11^h\ 8^m\ 8^s$, its error on Greenwich mean time being $52^m\ 40^s$ fast. Index error $= +2'\ 2''$. Height of eye $= 25$ feet. Find the latitude. Ans. Lat. $= 12°\ 40'$ N

3. On May 24, 1899, in latitude, by dead reckoning, $51°\ 30'$ N and longitude $9°\ 35'$ W, an altitude of the star Spica (α Virginis) observed near the time of meridian passage was $27°\ 47'\ 10''$. The chronometer at the instant of observation indicated $10^h\ 13^m\ 30^s$ correct Greenwich mean time. Index error $= +4'\ 50''$. Height of eye $= 18$ feet. Required, the latitude. Ans. Lat. $= 51°\ 22'$ N

4. On November 12, 1899, an altitude of the sun's lower limb observed near the meridian was $56°\ 32'\ 40''$. Index error $= +4'\ 49''$. Height of eye $= 33$ feet. Chronometer at instant of observation $= 18^h\ 10^m\ 33^s$, its error on Greenwich mean time being $3^m\ 33^s$ slow. Latitude in, by dead reckoning $= 14°\ 12'$ N. Longitude $= 90°\ 35'$ E. Required, the latitude. Ans. Lat. $= 14°\ 35'$ N

5. On March 31, 1899, in latitude, by dead reckoning, $42°\ 15'$ N and longitude $70°\ 55'$ W, an altitude of the star Sirius (α Canis Majoris) observed near the time of transit was $30°\ 50'\ 20''$. Correct local mean time at instant of observation $= 6^h\ 30^m\ 30^s$. Index error $= +2'\ 40''$. Height of eye $= 24$ feet. Find the latitude. Ans. Lat. $= 42°\ 20'$ N

6. On November 18, 1899, an altitude of the star Regulus (α Leonis) observed near the meridian was 42° 40′ 20″. Index error = − 4′ 19″. Height of eye = 22 feet. The Greenwich date corresponding to the time of measuring the altitude was November 17, 16^h 30^m. Latitude in, by dead reckoning = 34° 25′ S. Longitude = 18° 45′ E. Required, the latitude. Ans. Lat. = 34° 30′ S

7. On September 28, 1899, in latitude, by dead reckoning, 50° 45′ N and longitude 12° 58′ E, an altitude of the star Fomalhaut (α Pis. Aust.) observed near the meridian was 8° 52′. A watch that was 10^m 52^s slow on local mean time indicated 10^h 50^m at the instant of observation. Index error = − 1′ 39″. Height of eye = 30 feet. Find the latitude. Ans. Lat. = 50° 45′ N

LATITUDE BY CHANGE OF ALTITUDE NEAR THE PRIME VERTICAL

34. The chief requirement in all the foregoing methods of determining the latitude is that the observed body shall be on or near the meridian; but occasions may arise when it becomes important to find the latitude when the sun is on the prime vertical, or nearly east or west. This may be accomplished by computing the latitude according to the following formula:

$$\cos \text{latitude} = \frac{C \times H \times \sec A}{T},$$

in which C = a constant, the logarithm of which is 8.82390;
H = difference between the observed altitudes;
A = amplitude of the sun;
T = interval of time between the two observations.

This formula, combined with the order of procedure for observations, may be expressed by the following rule:

Rule.—*Observe the sun when it is on or very near the prime vertical by measuring two altitudes at short intervals (3 or 4 minutes). Note the time, by watch, when each altitude is measured. If the bearing of the sun is not exactly true east or west, note its amplitude while waiting for the second observation. Reduce the difference of the times and the altitudes to seconds. Then, to the constant logarithm 8.82390 add the log of the difference of altitudes, the a. c. log of interval in time, and the log*

secant of the amplitude. The sum of these logs will be the log cosine of the latitude.

According to *Nautical Astronomy*, Part 1, the amplitude of the sun, or any other celestial body, is measured along the horizon north or south from the prime vertical. Thus, if the true bearing of the sun is N 85° W, the amplitude is 90 − 85° = W 5° N, or simply 5° N.

EXAMPLE 1.—On June 29, 1899, in latitude, by dead reckoning, 32° 28′ N and longitude 55° 30′ W, two altitudes of the sun's lower limb were measured about 8:20 A. M. The first altitude taken was 39° 6′ and the second 39° 46′, the corresponding times being $8^h\ 18^m$ and $8^h\ 21^m\ 10^s$, respectively. The amplitude of the sun, corrected for errors of compass, was E 4° S. Required, the latitude.

SOLUTION.—

1st Alt. = 39° 6′	Corres. time = $8^h\ 18^m\ 0^s$	
2d Alt. = 39° 46′	Corres. time = $8^h\ 21^m\ 10^s$	
Diff. = 0° 40′ = 2,400″	Diff. = $0^h\ 3^m\ 10^s = 190^s$	

Constant log =	8.82390
log 2,400 =	3.38021
a. c. log 190 =	7.72125
log sec 4° =	0.00106
log cos Lat. =	9.92642
Lat. required =	32° 25′ N. Ans.

EXAMPLE 2.—On August 17, 1899, two altitudes of the sun's lower limb measured in the afternoon were as follows: 22° 35′ 40″ and 22° 4′ 10″; corresponding times, by watch: $5^h\ 12^m\ 19^s$ and $5^h\ 15^m\ 10^s$. The latitude by account was 42° 3′ N. The true amplitude of the sun at observation was W 8° N. Find the latitude.

SOLUTION.—

1st Alt. = 22° 35′ 40″	Corres. time = $5^h\ 12^m\ 19^s$
2d Alt. = 22° 4′ 10″	Corres. time = $5^h\ 15^m\ 10^s$
Diff. = 31′ 30″ = 1,890″	Diff. = $2^m\ 51^s = 171^s$

Constant log =	8.82390
log 1,890 =	3.27646
a. c. log 171 =	7.76700
log sec 8° =	0.00425
log cos Lat. =	9.87161
Lat. required =	41° 55′ N. Ans.

35. This method, which gives the best results in high latitudes, is, however, only approximate, and should not be relied on to any great extent; it is quite useful in connection with a method to be described that is known as "Sumner's method." The nearer the sun is to the prime vertical, the more satisfactory will be the result.

It will be observed that this method is absolutely independent of the Nautical Almanac, and no corrections of any kind are necessary except if the amplitude is taken by compass it should be corrected for whatever error the compass may have.

LATITUDE BY THE POLE STAR

36. The following method of determining the latitude by the pole star, though restricted to the northern hemisphere, may always be resorted to *at any time of the night* when the star is visible and the horizon distinctly defined, provided the local apparent or mean time at the instant of observation is known. The order of procedure to be complied with when using this method may be embodied in the following rule:

Rule.—*At the instant of measuring the altitude, note the time indicated by the chronometer (or watch previously compared with chronometer). Reduce the observed altitude to true, and from the result subtract 1 minute. Reduce the recorded time at observation to local sidereal time, according to previous instructions. With the sidereal time found, find, from the Nautical Tables, page 165, the first correction with its proper sign. If the sign is +, the correction should be added to the true altitude; if −, it should be subtracted; the result is the approximate value of the latitude. With the true altitude and local sidereal time, take out a second correction from the table next following; and, with the day of the month and local sidereal time, take out a third correction from the third table. These two corrections, added to the approximate latitude previously found, will produce a comparatively trustworthy value of the required latitude.*

EXAMPLE 1.—On August 3, 1899, at 1^h 10^m A. M., local mean time, in longitude 26° W, an observed altitude of Polaris was 56° 47′ 40″. Index error = + 1′ 25″. Height of eye = 20 feet. Find the latitude.

SOLUTION.—First find the Greenwich date, and then the corresponding local sidereal time. Thus,

L. M. T.	=	13^h 10^m
Long. (W) in time	=	$+1^h$ 44^m
G. D., Aug. 2	=	14^h 54^m
Sid. time G. M. N.	=	8^h 43^m 27.1^s
Corr. for 14^h 54^m	=	2^m 26.9^s (N. A.)
R. A. M. S.	=	8^h 45^m 54^s
L. M. T.	=	13^h 10^m 0^s
L. Sid. T.	=	21^h 55^m 54^s

Obs. Alt. ✳	=	56° 47′ 40″
I. E	=	+ 1′ 25″
		56° 49′ 5″
Dip	=	− 4′ 23″
		56° 44′ 42″
Ref.	=	− 0′ 37″
True Alt	=	56° 44′ 5″
Constant	=	− 1′ 0″
		56° 43′ 5″
1st Corr.	=	− 45′ 26″ (N. T., page 165)
Approx. Lat.	=	55° 57′ 39″
2d Corr.	=	+ 42″ (N. T., page 166)
3d Corr.	=	+ 39″ (N. T., page 166)
Lat. required	=	55° 59′ N. Ans.

EXAMPLE 2.—On September 20, 1899, in longitude 124° 37′ W, the observed altitude of Polaris was 36° 42′ 30″. The Greenwich mean time at the instant of observation, as taken from the chronometer, was 19^h 20^m 15^s. Index error = − 3′ 10″. Height of eye = 22 feet. Required, the latitude.

SOLUTION.—Proceed as in the foregoing example. Thus,

G. D., Sept. 20	=	19^h 20^m 15^s
Long. (W) in time	=	8^h 18^m 28^s
L. M. T.	=	11^h 1^m 47^s
Sid. Time G. M. N.	=	11^h 56^m 38.24^s
Corr. for 19^h 20^m, Table III	=	3^m 10.6^s (N. A.)
R. A. M. S.	=	11^h 59^m 49^s
L. M. T.	=	11^h 1^m 47^s
Sid. time	=	23^h 1^m 36^s

Obs. Alt. ✳	= 36° 42′ 30″
I. E.	= − 3′ 10″
	36° 39′ 20″
Dip	= − 4′ 36″
	36° 34′ 44″
Ref.	= − 1′ 17″
True Alt.	= 36° 33′ 27″
Constant	= − 1′ 0″
	36° 32′ 27″
1st Corr.	= − 59′ 43″
Approx. Lat.	= 35° 32′ 44″
2d Corr.	= + 11″
3d Corr.	= + 48″
Lat. required	= 35° 33.7′ N. Ans.

Example 3.—On March 26, 1899, in longitude 30° 26′ E, an altitude of Polaris observed in an artificial horizon was 84° 44′. Index error = + 5′ 20″. The chronometer at the instant of observation was $8^h\ 2^m\ 12^s$, its error on Greenwich mean time being $4^m\ 18^s$ slow. Find the latitude.

Solution.—Proceed as before. Thus,

Chron.	= $8^h\ 2^m\ 12^s$
Error (slow)	= + $4^m\ 18^s$
G. D., Mar. 26	= $8^h\ 6^m\ 30^s$
Long. (E) in time	= $2^h\ 1^m\ 44^s$
L. M. T.	= $10^h\ 8^m\ 14^s$
Sid. time G. M. N.	= $0^h\ 14^m\ 51.36^s$
Corr. for $8^h\ 6\frac{1}{2}^m$, Table III	= $1^m\ 19.9^s$ (N. A.)
R. A. M. S.	= $0^h\ 16^m\ 11.3^s$
L. M. T.	= $10^h\ 8^m\ 14^s$
Sid. time	= $10^h\ 24^m\ 25^s$
Obs. double Alt. ✳	= 84° 44′ 0″
I. E.	= + 5′ 20″
	2)84° 49′ 20″
App. Alt. ✳	= 42° 24′ 40″
Ref.	= − 1′ 2″
True Alt.	= 42° 23′ 38″
Constant	= − 1′ 0″
App. Alt. ✳	= 42° 22′ 38″
1st Corr.	= + 52′ 9″
Approx. Lat.	= 43° 14′ 47″
2d Corr.	= + 20″
3d Corr.	= + 1′ 33″
Lat. required	= 43° 16.7′ N. Ans.

37. Simplification of Method.—At the time of the pole star's upper or lower transit, as well as at its greatest eastern or western elongation, the process of computing the latitude may be greatly simplified by reason of the star's proximity to the north celestial pole. In order to explain this, let mn, Fig. 7, represent the observer's meridian, HH' the horizon, S and S' the position of the star at its upper and its lower transit, and E and E' the star's position when at its greatest western and at its greatest eastern elongation. Now, when the star is at E or E', it is evident that the true altitude is equal to the altitude of the pole or equal to the latitude of the observer, since the latitude of any place on the earth is equal to the true altitude of the pole above the horizon. Therefore, when Polaris is situated at either E or E', or, when Polaris and Alioth c, the third star in the constellation Ursa Major (Dipper), are on the same horizontal line, the simple reduction of its measured altitude to true would at once give the latitude of the observer. Again, should the altitude of Polaris be measured at S when at its upper transit (when Alioth is vertically below it), the latitude would be obtained by *subtracting* from the true altitude the polar distance of the star, which at present is equal to 72′, nearly; if measured when at S', or when Polaris is at its lower transit (when Alioth is vertically above it), the polar distance *added* to the true altitude would be equal to the latitude of the observer.

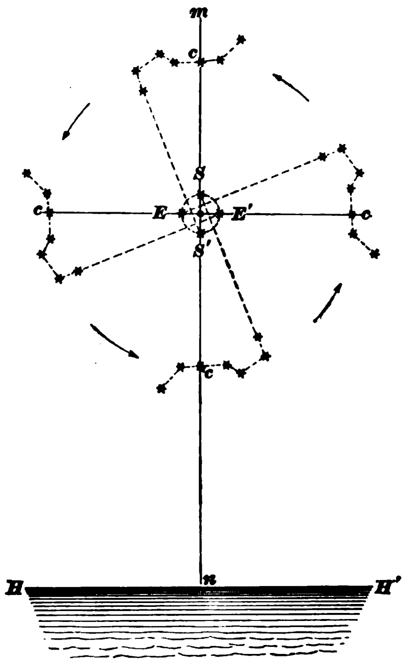


FIG. 7

Since the pole star performs its apparent daily circuit around the celestial pole in 24 sidereal hours, it follows that an interval of 6 hours is required to pass from one of the positions indicated in Fig. 7 to the next. Consequently, it is only at every sixth hour that a simplification in the process of finding the latitude by Polaris is possible. At any intermediate position, the latitude should be determined according to the rule of the preceding article, which may be classified as a less intricate form of reduction to the meridian.

The latitude thus found is, of course, only an approximation (correct, perhaps, only to within 4 or 5 minutes of arc), but at the same time it may serve as a useful check on the latitude by account, especially so, after a continued run in fog and thick weather. The main difficulty in observing the pole star (and, for that matter, any other star) is to measure the altitude, because of the indistinctness of the sea horizon at night and the small size of the star. It requires considerable practice with the sextant before altitudes measured on the sea horizon at night can be considered trustworthy.

38. Additional Method by Polaris.—On the last page of the Nautical Almanac for each year is given a table for computing the latitude approximately from an observed altitude of Polaris at any time (whether the star is on the meridian or not), its hour angle being known to a close approximation. As full instructions accompany the table, they need not be repeated here. However, it is well to remember that the table given in the Nautical Almanac is good only for that year and should not be used in other years without the proper corrections.

39. Present and Future Pole Stars.—The reason for the precaution mentioned in the preceding article is that the pole star is gradually changing its position relatively to the celestial pole, which makes the formation of new values of the table necessary; the annual change of the declination of Polaris is 19″ (increasing), and that of its right ascension 25^s (increasing). Our present pole star did not always and will not forever bear the distinction of being the most important

of stars in the northern celestial hemisphere. Owing to the motion of the pole, as described in *Nautical Astronomy*, Part 1, Polaris will in course of time, about 2095 A. D., approach to within 28′ of the north celestial pole, and will then commence to recede from it. Hence, up to that year, the polar distance of the present pole star will decrease gradually until its value is only 28′, after which it will increase again. At the time of Hipparchus (156 B. C.) this star was 12°, and in the year 1785 it was 2° 2′, distant from the pole. Two thousand years ago the star β Ursæ Minoris was the pole star, and about 2,300 years before the Christian era the star α Draconis was not more than 10′ from the celestial pole, while 12,000 years from the present time the brilliant star Vega (α Lyræ) will be within 5° of it. These changes, requiring thousands of years, are caused by the precession of the equinoxes.

EXAMPLES FOR PRACTICE

1. On October 29, 1899, in longitude 179° 14′ E, the observed altitude of Polaris was 19° 25′. Index error = − 3′ 20″. Height of eye = 23 feet. Greenwich mean time at instant of observation = 23^h 24^m 10^s. Required, the latitude. Ans. Lat. = 18° 1.6′ N

2. On December 9, 1899, at 7^h 10^m 30^s P. M., local mean time, the observed altitude of Polaris was 10° 17′ 10″. Index error = + 3′ 20″. Height of eye = 26 feet. Longitude = 37° W. Find the latitude. Ans. Lat. = 8° 58.7′ N

3. On April 27, 1899, at 11^h 24^m 6^s P. M., local mean time, the observed altitude of Polaris taken in an artificial horizon was 78° 20′ 10″. Index error = + 2′ 10″. Longitude = 42° 20′ W. Find the latitude. Ans. Lat. = 40° 23.3′ N

4. On March 15, 1900, an altitude of Polaris was measured when exactly on a horizontal line with Alioth; it was found to be 40° 15′ 30″. Index error = − 1′ 40″. Height of eye = 14 feet. Find the latitude. Ans. Lat. = 40° 9′ N

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40. Compound Altitudes.—In the foregoing examples of methods for determining the latitude of an observer, a single altitude of the celestial object observed has uniformly been regarded as the altitude at the time. However, as it is not always possible to measure an altitude with sufficient

precision, it is advisable, where a certain degree of accuracy is required, to take several altitudes, or compound altitudes (usually three or five), in rapid succession—that is, within a minute or two of one another—and to note the corresponding times either on a chronometer or on a watch; the interval between these observations should be as nearly equal as practicable. The mean of the altitudes thus observed is then considered as the correct observed altitude corresponding to the mean of the times.

41. To illustrate this, assume that an observer is about to measure an altitude of a star near the meridian, or ex-meridian altitude, as it is commonly called. An assistant is stationed in the chronometer room and is ready to note the time when the prearranged signal is given (which may consist of either a call or the touching of an electric push button connected with a bell in the chronometer room), the result being as follows:

ALTITUDES		CHRONOMETER
24° 18′ 0″		$4^h\ 40^m\ 0^s$
18′ 30″		$41^m\ 10^s$
19′ 10″		$42^m\ 5^s$
19′ 50″		$43^m\ 0^s$
20′ 30″		$44^m\ 17^s$
5)96′ 0″		$5)210^m\ 32^s$
24° 19′ 12″	= mean =	$4^h\ 42^m\ 6.4^s$

Since the mean of these altitudes and the corresponding chronometer times are likely to be more accurate than any single observation, the observer now proceeds as if the observed altitude of the star were 24° 19′ 12″ and the corresponding time by the chronometer, $4^h\ 42^m\ 6.4^s$.

42. Hack Chronometer.—In measuring a set of altitudes, the chronometer is not always consulted directly, but a good second's watch, or Hack chronometer, is used. The mean of the times by watch corresponding to the mean of the altitudes being found, the watch is then compared with the chronometer and its error on chronometer time ascertained.

This error being allowed for, the time by chronometer corresponding to the mean of the altitudes is obtained; or, the error of the watch may be found by comparing it with the chronometer immediately before the observations are taken. Whether the comparison takes place before or after, it should be within a short interval of the observations, and the observer should never neglect to compare the two timepieces at each observation, no matter how frequently they may occur.

LONGITUDE AND AZIMUTH

DETERMINATION OF LONGITUDE

LONGITUDE BY CHRONOMETER

(*Time Sight of the Sun*)

1. Explanation.—The determination of longitude at sea is a problem of first consequence to the navigator. From statements previously made, it is known that the longitude of any place on the surface of the globe is established as soon as the time at that place and the time at Greenwich at the same instant is determined. The difference between these times, whether mean or apparent, converted into degrees, minutes, and seconds, is the desired longitude, which is *west* when the time at Greenwich is *greater* than that at the place, but *east* if the time at Greenwich is *less* than the local time. Now, the chronometer, when properly corrected for error and accumulated rate, will furnish the time at Greenwich; hence, the problem of determining longitude is simply a problem of determining the local time at ship. How this is accomplished, by means of observations of celestial bodies, will now be explained.

According to a previous statement, it is known that at any instant

apparent solar time = hour angle of the true sun

From this it follows that when the sun's hour angle is found, the local apparent time is at once determined, which, by the application of the equation of time, may be converted

into local mean time for comparison with the Greenwich mean time as registered by the chronometer.

2. Derivation of Formula for Hour Angle.—In Fig. 1, let S represent the celestial body to be observed, SA its altitude, and SD its declination. In the spherical triangle SPZ, then, $SZ = (90° - \text{altitude})$ = zenith distance, $SP = (90° - \text{declination})$ = polar distance, and $ZP = 90° - \text{latitude}$; hence, all three sides of the triangle are

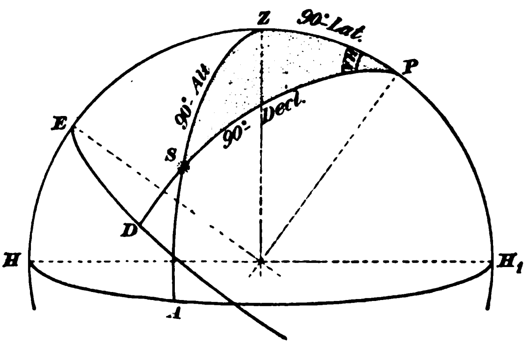


Fig. 1

known. Therefore, the hour angle (H. A.) is conveniently found by the application of the general formula,

$$\cos A = \frac{\cos a - \cos b \cos c}{\sin b \sin c},$$

which, when applied to Fig. 1, will appear as follows:

$$\cos \text{H. A.} = \frac{\cos(90° - \text{alt.}) - \cos(90° - \text{decl.})\cos(90° - \text{lat.})}{\sin(90° - \text{decl.}) \sin(90° - \text{lat.})},$$

or
$$\cos \text{H. A.} = \frac{\sin a - \cos p \sin l}{\sin p \cos l},$$

in which a = true altitude of observed body;
l = latitude of place;
p = polar distance of observed body.

Subtracting each side of the equation from 1,

$$1 - \cos \text{H. A.} = 1 - \frac{\sin a - \cos p \sin l}{\sin p \cos l};$$

whence, by trigonometry, the following transformation is effected:

$$2\sin^2\frac{\text{H. A.}}{2} = \frac{\sin p\cos l + \cos p\sin l - \sin a}{\sin p\cos l};$$

$$2\sin^2\frac{\text{H. A.}}{2} = \frac{\sin(p+l) - \sin a}{\sin p\cos l};$$

$$2\sin^2\frac{\text{H. A.}}{2} = \frac{2\cos\frac{1}{2}(p+l+a)\sin\frac{1}{2}(p+l-a)}{\sin p\cos l}$$

Now, if $\frac{1}{2}(p+l+a) = S,$

then $\frac{1}{2}(p+l-a) = S-a$

Substituting these values and canceling,

$$\sin^2\frac{\text{H. A.}}{2} = \frac{\cos S\sin(S-a)}{\sin p\cos l},$$

or $$\sin^2\frac{\text{H. A.}}{2} = \operatorname{cosec} p\sec l\cos S\sin(S-a);$$

whence, $$\sin\frac{\text{H. A.}}{2} = \sqrt{\operatorname{cosec} p\sec l\cos S\sin(S-a)},$$

which is the formula in common use for computing the hour angle in problems of longitude and problems relating to time in general.

3. When Hour Angles Should Be Observed.—The most favorable position of a celestial body for finding the hour angle from its altitude is when it is near or on the prime vertical. A small error in the latitude will then have very little or no effect on the hour angle, and the error in the hour angle corresponding to a small error in the altitude will be the least. Moreover, since a celestial body moves much faster at or about the time of rising and setting, it is possible then to observe its altitude with great precision. The error in longitude produced by an error in the measured altitude increases with the latitude. Thus, in latitude 60° N or S, for example, an error of 1′ in the altitude will cause a corresponding error of at least 10^s of time in the resulting longitude. The farther away the observed body is from the prime vertical, the more accurately should the observer know his latitude. Furthermore, in order that the result shall be as correct as possible, it is advisable to take several altitudes at short intervals, noting the chronometer time at each, and to use the mean as the observed altitude and the mean of the

times as the chronometer time. Finally, when measuring altitudes for the determination of hour angles, do not select times when the sun or the observed body is near the horizon and the atmosphere is not clear. Fog and haziness increase the refraction to a great extent; therefore, it is best to avoid low altitudes if possible. The selected body should be at least 14° above the horizon before its altitude is measured.

4. Directions for Finding Longitude.—From what has been said in the preceding articles, the following rule may be formulated for determining the longitude of a ship by a simultaneous observation of the sun and the ship's chronometer:

Rule.—*Measure a set of altitudes (usually three will suffice) of the sun in the forenoon or afternoon when it bears as nearly east or west as practicable, and note the corresponding time, either directly on the chronometer or by a watch.*

Correct the chronometer time for error and accumulated rate. The result will be the Greenwich mean time, or Greenwich date, at the instant of observation.

Reduce the observed altitude to true by applying the usual corrections. Find the latitude of the ship by dead reckoning from the last fix up to the time of taking the sight.

Take out the equation of time and correct it for the Greenwich date.

In a similar manner, correct the sun's declination for the Greenwich date, and find the polar distance (p) as follows:

If the declination and the latitude are both north,
If the declination and the latitude are both south, $\Big\}$ $p = 90° -$ *declination.*

If the declination is north and the latitude south,
If the declination is south and the latitude north, $\Big\}$ $p = 90° +$ *declination.*

There have now been obtained the three quantities: a (= altitude), p (= polar distance), and l (= latitude). Therefore, S is found by taking half the sum of a, p, and l

[$= \frac{1}{2}(a + p + l)$], and $(S - a)$ by subtracting the altitude from the aforesaid half sum.

Then calculate the hour angle by the given formula, adding the log cosec p, log sec l, log cos S, and log sin $(S - a)$. The sum divided by 2 is the log sine for half the hour angle.

5. The hour angle having been found, the local apparent time is readily deduced by remembering that the sun's *westerly* hour angle is equal to local apparent time. Hence, if the observation is made in the forenoon, when the sun is at S, Fig. 2, and the hour angle nPS is easterly, it will be necessary to subtract this interval from 24 hours in order to obtain the westerly hour angle nS_1mS, reckoned from noon of the preceding day, which is equal to the local apparent time. But if the observation is made in the afternoon, or when the sun is at S_1, it is evident that the hour angle nPS_1 is equal to the required local apparent time.

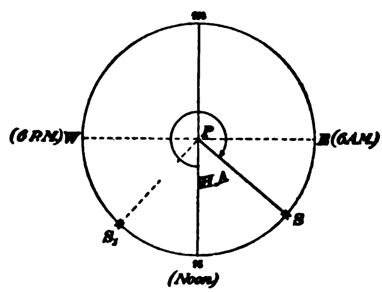


FIG. 2

The local apparent time having been determined, the corresponding local mean time is found by applying the equation of time according to its sign. The difference between the local mean time and the Greenwich mean time converted into degrees, minutes, and seconds will be the required longitude of the ship. If the Greenwich mean time is greater than the local mean time, the longitude is *west;* if the local mean time is greater than the Greenwich mean time, the longitude is *east*.

EXAMPLE.—On February 24, 1899, at about $8^h\ 50^m$ A. M., the observed altitude of the sun's upper limb was $19^\circ\ 8'\ 40''$. Index error $= +2'\ 35''$. Height of eye = 20 feet. Latitude in, by dead reckoning $= 46^\circ\ 48'$ N. Longitude uncertain, but estimated at $65^\circ\ 40'$ W. At the instant of observation the chronometer indicated $1^h\ 18^m\ 11^s$, its error on Greenwich mean time being $2^m\ 5^s$ slow. Required, the longitude.

SOLUTION.—First find an approximate Greenwich date. Thus,

$$\begin{array}{rl}
\text{L. M. T. at ship, Feb. 24} = & 8^h\ 50^m\ 0^s \text{ A. M.}\\
\text{Or, Feb. 23} = & 20^h\ 50^m\ 0^s \text{ P. M.}\\
\text{Long. } 65^\circ\ 40' \text{ W. in time} = & +\ 4^h\ 22^m\ 40^s\\
\hline
\text{Approx. G. D., Feb. 23} = & 25^h\ 12^m\ 40^s\\
\text{Or, Feb. 24} = & 1^h\ 12^m\ 40^s\\
\text{Chron., Feb. 24} = & 1^h\ 18^m\ 11^s\\
\text{Error (slow)} = & +\quad 2^m\ 5^s\\
\hline
\text{G. D.; or G. M. T., Feb. 24} = & 1^h\ 20^m\ 16^s
\end{array}$$

Then, from the Nautical Almanac, find the declination and the equation of time. Reduce the observed altitude to true, and find the quantities S and $(S - a)$. Thus,

$$\begin{array}{rl}
\odot \text{ Decl., Feb. 24} = & \text{S } 9^\circ\ 25'\ 38.5''\\
\text{Corr.} = & -\quad 1'\ 12''\\
\hline
\text{Corr. Decl.} = & \text{S } 9^\circ\ 24'\ 26''\\
 & 90^\circ\ 0'\ 0''\\
\hline
\text{P. D.} = & 99^\circ\ 24'\ 26''\\
\text{Eq. of T., Feb. 24} = & 13^m\ 24.6^s\\
\text{Corr.} = & -\quad 0.5^s\\
\hline
\text{Corr. Eq. of T.} = & 13^m\ 24^s\ (+)\\
\text{Obs. Alt. } \underline{\odot} = & 19^\circ\ 8'\ 40''\\
\text{I. E.} = & +\quad 2'\ 35''\\
\hline
 & 19^\circ\ 11'\ 15''\\
\text{Dip} = & -\quad 4'\ 23''\\
\hline
 & 19^\circ\ 6'\ 52''\\
\odot \text{ S. D.} = & -\quad 16'\ 12''\\
\hline
 & 18^\circ\ 50'\ 40''\\
\text{Ref.} = & -\quad 2'\ 43''\\
\hline
 & 18^\circ\ 47'\ 57''\\
\odot \text{ Par.} = & +\quad 8''\\
\hline
a = & 18^\circ\ 48'\ 5''
\end{array}
\qquad
\begin{array}{rl}
\text{Change in } 1^h = & 55.4''\\
 & \times\ 1.3^h\\
\hline
\text{Corr.} = & 72.02''\\
\\
\text{Change in } 1^h = & 0.38^s\\
 & \times\ 1.3^h\\
\hline
\text{Corr.} = & 0.494^s\\
\\
S = & \dfrac{p + l + a}{2}\\
p = & 99^\circ\ 24'\ 26''\\
l = & 46^\circ\ 48'\ 0''\\
a = & 18^\circ\ 48'\ 5''\\
\hline
 & 2)165^\circ\ 0'\ 31''\\
S = & 82^\circ\ 30'\ 15''\\
S - a = & 63^\circ\ 42'\ 10''
\end{array}$$

Then compute the hour angle according to the formula of Art. **2.** Thus,

$$\sin \tfrac{1}{2} \text{ H. A.} = \sqrt{\operatorname{cosec} p \sec l \cos S \sin (S - a)}$$

$$\begin{array}{rl}
\log \operatorname{cosec} 99^\circ\ 24'\ 26'' = & 0.00588\\
\log \sec 46^\circ\ 48'\ 0'' = & 0.16460\\
\log \cos 82^\circ\ 30'\ 15'' = & 9.11546\\
\log \sin 63^\circ\ 42'\ 10'' = & 9.95255\\
\hline
 & 2)19.23849\\
\log \sin \tfrac{1}{2} \text{ H. A.} = & 9.61924\\
\tfrac{1}{2} \text{ H. A.} = & 24^\circ\ 35'\ 30''\\
\text{H. A.} = & 49^\circ\ 11' = 3^h\ 16^m\ 44^s
\end{array}$$

This is the sun's easterly hour angle (or the angle $n P S$, Fig. 3), because the sight was taken in the forenoon; but, in order to compare it with the Greenwich mean time, it must be subtracted from 24^h, whence the following result is obtained:

$$
\begin{array}{rcll}
 & & 24^h\ 0^m\ 0^s & \\
\text{H. A., east} & = & \underline{\ 3^h\ 16^m\ 44^s} & \\
\text{L. App. T., Feb. 23} & = & 20^h\ 43^m\ 16^s & \text{P. M.} \\
\text{Eq. of T.} & = & \underline{+\ \ 13^m\ 24^s} & \\
\text{L. M. T., Feb. 23} & = & 20^h\ 56^m\ 40^s & \text{P. M.} \\
\text{G. M. T., Feb. 23} & = & \underline{25^h\ 20^m\ 16^s} & \text{P. M.} \\
\text{Diff.} & = & 4^h\ 23^m\ 36^s & \\
\text{Long.} & = & 65°\ 54'\ \text{W.} & \text{Ans.}
\end{array}
$$

6. The latter part of the process of finding the hour angle may be somewhat simplified by the use of the A. M. and P. M. columns, found opposite the sine column in the tables of Logarithmic Functions. These columns give the hour angle, expressed in time, *directly* from the log sin ½ H. A., the A. M. column being used when the observation is made in the forenoon, and the P. M. column when the observation is made in the afternoon. This may be exemplified by referring to the foregoing example, in which log sin ½ H. A. = 9.61924. In the A. M. column of the tables of Logarithmic Functions, opposite sin 9.61911 will be found 8^h 43^m 20^s, and by interpolation (to be described later), the exact time corresponding to the given log is found to be 8^h 43^m 16^s A. M. This is the local apparent time, February 24, A. M., or the angle $m P S$, Fig. 3. Applying the equation of time to this, will give the corresponding local mean time. Now, the Greenwich mean time, as indicated by the chronometer, is February 24, 1^h 20^m 16^s P. M., or the angle $n P G$ ($m n$ being the meridian). By adding 12 hours to this time,

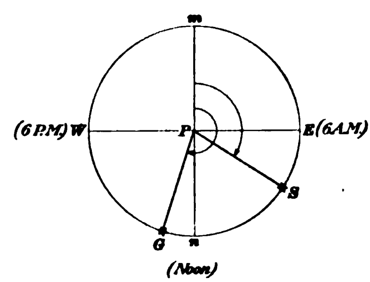


FIG. 3

Greenwich mean time (counted from the same point as the local time) is found to be February 24, $13^h\ 20^m\ 16^s$ A. M., civil time, whence the longitude is found as before by comparing the local mean time with the Greenwich mean time, and is named according to directions already given.

The solution of the foregoing example will now appear as follows:

$$\log \sin \tfrac{1}{2} \text{ H. A.} = 9.61924$$

$$\begin{array}{rcll}
\text{L. App. T., Feb. 24} & = & 8^h\ 43^m\ 16^s \text{ A. M.} & \text{(A. M. column)} \\
\text{Eq. of T.} & = & +\ 13^m\ 24^s & \\
\hline
\text{L. M. T., Feb. 24} & = & 8^h\ 56^m\ 40^s \text{ A. M.} & \multirow{2}{*}{\Big\}\text{Fig. 3}} \\
\text{G. M. T., Feb. 24} & = & 13^h\ 20^m\ 16^s \text{ A. M.} & \\
\hline
\text{Diff.} & = & 4^h\ 23^m\ 36^s & \\
\text{Long.} & = & 65^\circ\ 54'\ \text{W} &
\end{array}$$

This result agrees exactly with that obtained before.

NOTE.—It should be borne in mind that when comparing the Greenwich mean time with the local mean time, both must be either P. M. or A. M. An A. M. interval cannot be compared with a P. M. interval, or vice versa. In this example it will be observed that P. M. intervals are used in the first solution and A. M. intervals in the second. In connection with examples of computing the hour angle, it is advisable to make use of a rough sketch or diagram (Rodenian Time Diagram) similar to Figs. 3 and 4. This will greatly aid the beginner in avoiding mistakes and materially assist him in the correct determination of the time, which, as a general rule, is his greatest stumbling block.

7. Comparison of Apparent Times.—It is evident that the longitude is just as readily found by comparing the apparent time at Greenwich with the ship's apparent time. Thus, in the foregoing example,

$$\begin{array}{rcll}
\text{G. M. T., Feb. 24} & = & 13^h\ 20^m\ 16^s \text{ A. M.} & \\
\text{Eq. of T.} & = & -\ 13^m\ 24^s & \left(\begin{array}{c}\text{Subtractive from M. T.}\\ \text{according to N. A}\end{array}\right) \\
\hline
\text{G. App. T., Feb. 24} & = & 13^h\ \ 6^m\ 52^s \text{ A. M.} & \\
\text{L. App. T., Feb. 24} & = & 8^h\ 43^m\ 16^s \text{ A. M.} & \\
\hline
\text{Diff.} & = & 4^h\ 23^m\ 36^s & \\
\text{Long.} & = & 65^\circ\ 54'\ \text{W} &
\end{array}$$

The longitude thus found should evidently agree exactly with that derived by comparing the corresponding mean times.

Example.—On October 1, 1899, in latitude and longitude, by dead reckoning, 40° 30′ N and 59° W, a set of altitudes of the sun's lower limb taken at about 8 o'clock in the morning was as follows: 17° 9′ 30″, 17° 15′ 50″, and 17° 20′ 10″. The corresponding chronometer times were $11^h\ 33^m\ 40^s$, $11^h\ 34^m\ 20^s$, and $11^h\ 35^m\ 36^s$. Index error of sextant = − 3′ 10″. Height of eye = 15 feet. Error of chronometer on Greenwich mean time = $4^m\ 32^s$ fast. Find the longitude.

Solution.—First find the mean of altitudes and chronometer times. Then proceed according to directions given in Arts. 4 and 5. Thus,

	Altitude		*Chronometer*
	17° 9′ 30″		$11^h\ 33^m\ 40^s$
	17° 15′ 50″		$11^h\ 34^m\ 20^s$
	17° 20′ 10″		$11^h\ 35^m\ 36^s$
	3)51° 45′ 30″		3)$34^h\ 43^m\ 36^s$
Obs. Alt. $\underline{\odot}$ =	17° 15′ 10″	Chron. =	$11^h\ 34^m\ 32^s$
I. E. =	− 3′ 10″	Error (fast) =	− $4^m\ 32^s$
	17° 12′ 0″	G. M. T., Oct. 1 =	$11^h\ 30^m\ 0^s$ A. M.
Dip =	− 3′ 48″		
	17° 8′ 12″		
$\odot$ S. D. =	+ 16′ 1″		
	17° 24′ 13″		
Ref. =	− 3′ 3″		
	17° 21′ 10″		
$\odot$ Par. =	+ 0′ 8″		
a =	17° 21′ 18″		
p =	93° 11′ 57″		
l =	40° 30′ 0″		
	2)151° 3′ 15″		
S =	75° 31′ 37″		
$S - a$ =	58° 10′ 19″		

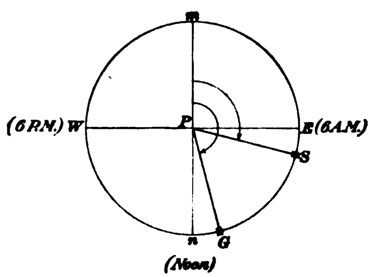


Fig. 4

$\odot$ Decl., Oct. 1 =	S 3° 12′ 26″	Change in 1^h =	58.3″
Corr. =	− 29″		× 0.5^h
$\odot$ Corr. Decl. =	S 3° 11′ 57″	Corr. =	29.1″
	90° 0′ 0″		
P. D. =	93° 11′ 57″		

Eq. of T., Oct. 1 =	$10^m\ 19.4^s$	Change in 1^h =	0.79^s
Corr. =	− 0.4^s		× 0.5^h
Corr. Eq. of T. =	$10^m\ 19^s$ (−)	Corr. =	0.395^s

log cosec 93° 11′ 57″	=	0.00068
log sec 40° 30′ 0″	=	0.11895
log cos 75° 31′ 37″	=	9.39782
log sin 58° 10′ 9″	=	9.92923
		2)19.44668
log sin ½ H. A.	=	9.72334

Whence,	L. App. T.	=	$7^h\ 44^m\ 34^s$ (A. M. column)
	Eq. of T.	=	$-\ 10^m\ 19^s$
	L. M. T., Oct. 1	=	$7^h\ 34^m\ 15^s$ A. M. } Fig. 4
	G. M. T., Oct. 1	=	$11^h\ 30^m\ 0^s$ A. M. } Fig. 4
	Diff.	=	$3^h\ 55^m\ 45^s$
	Long.	=	58° 56′ 15″ W. Ans.

8. Use of Proportional Parts.—When using the A. M. and P. M. columns of the tables of Logarithmic Functions, it frequently occurs that the logarithm by which the local apparent time is found does not agree with any of the logarithms in the sine column. In such cases, find the difference between the given log and the nearest log in the sine column, and apply this difference to the little table of proportional parts at the bottom of the page, opposite the letter of the column from which the logarithm was taken. Vertically above this will be found the number of seconds to be added to or subtracted from the time corresponding to the nearest log. When the given log is greater than the nearest log in the table, add the seconds obtained from the table below if seconds in column of times are increasing; otherwise, subtract them. This procedure is known as *interpolation*. In order to make this clearer, reference is made to the foregoing example, where the given log is 9.72334. The difference between this log and the nearest log in the table (9.72340) is 6. By inspecting the small table referred to, opposite the column marked "A," it is found that the nearest number is 5 and that vertically above is found 2^s. Now, since the hour angle is decreasing toward the bottom of the A. M. column, the hour angle corresponding to the given log must be greater than the one corresponding to 9.72340. Therefore, the 2^s is added to the $7^h\ 44^m$ 32 found in the A. M. column, thus making the local apparent time

equal to $7^h\ 44^m\ 34^s$. Had the difference between the given and the nearest smaller log (9.72320) been taken, the resulting hour angle would necessarily have been the same. In that case the difference is 14, and above 15 in the small table is found 6^s, which, when *subtracted* from $7^h\ 44^m\ 40^s$, will produce a local apparent time of $7^h\ 44^m\ 34^s$, as before. When using the A. M. and P. M. columns, particular attention should be paid to the decrease and the increase of the hour angle, and the seconds of time should be applied accordingly; and since 4 seconds of time is equal to 1′ of longitude, the importance of obtaining a correct value of the hour angle, expressed to the nearest second of time, will at once be fully realized.

EXAMPLE.—On January 17, 1899, about 3:50 P. M., an altitude of the sun's lower limb was 37° 3′ 30″. Index error = + 1′ 40″. Height of eye = 16 feet. At the instant of observation, the chronometer indicated $7^h\ 36^m\ 30^s$ P. M., its error on Greenwich mean time at noon on November 21, 1898, being $10^m\ 20.5^s$ fast, and its daily rate 3.5^s losing. The latitude in, by dead reckoning = 46° 30′ S. Required, the longitude.

SOLUTION.—First find the correct Greenwich mean time by applying to the chronometer time the original error and accumulated rate. Thus,

$$\begin{array}{rl} \text{Chron., Jan. 17} = & 7^h\ 36^m\ 30^s \\ \text{Error (fast)} = & -\quad 7^m\ \ 0^s \\ \hline \text{G. M. T., Jan. 17} = & 7^h\ 29^m\ 30^s \end{array}$$

$$\begin{array}{rr} \text{Nov.} & 9^d \\ \text{Dec.} & 31^d \\ \text{Jan.} & 17.3^d \\ \hline \text{Days elapsed} = & 57.3^d \\ \text{Daily rate} = & \times\ 3.5^s \\ \hline & 2865 \\ & 1719 \\ \hline & 60)200.55^s \end{array}$$

$$\begin{array}{rl} \text{Accumulated loss} = & 3^m\ 20.5^s \\ \text{Error, Nov. 21, 1898 (fast)} = & 10^m\ 20.5^s \\ \hline \text{Error, Jan. 17} = & 7^m\ \ 0^s\ \textit{fast} \end{array}$$

$$\begin{array}{rl} \odot\ \text{Decl., Jan. 17} = & \text{S } 20°\ 43'\ 39'' \\ \text{Corr.} = & -\qquad 3'\ 43'' \\ \hline \odot\ \text{Corr. Decl.} = & \text{S } 20°\ 39'\ 56'' \\ & \quad 90°\ \ 0'\ \ 0'' \\ \hline \text{P. D.} = & \quad 69°\ 20'\ \ 4'' \end{array}$$

$$\begin{array}{rr} \text{Change in } 1^h = & 29.7'' \\ & \times\ 7.5^h \\ \hline & 222.75'' \\ \text{Corr.} = & 3'\ 43'' \end{array}$$

$$
\begin{aligned}
\text{Eq of T., Jan. 17} &= 10^m\ 20.47^s \\
\text{Corr.} &= +\quad 6.15^s \\
\hline
\text{Corr. Eq. of T.} &= 10^m\ 26.6^s\ (+)
\end{aligned}
\qquad
\begin{aligned}
\text{Change in } 1^h &= 0.82^s \\
&\times 7.5^h \\
\hline
\text{Corr.} &= 6.150^s
\end{aligned}
$$

$$
\begin{aligned}
\text{Obs. Alt. } \odot &= 37^\circ\ 3'\ 30'' \\
\text{I. E.} &= +\quad 1'\ 40'' \\
\hline
&\ 37^\circ\ 5'\ 10'' \\
\text{Dip} &= -\quad 3'\ 55'' \\
\hline
&\ 37^\circ\ 1'\ 15'' \\
\odot\ \text{S. D.} &= +\ 16'\ 17'' \\
\hline
&\ 37^\circ\ 17'\ 32'' \\
\text{Ref.} &= -\quad 1'\ 16'' \\
\hline
&\ 37^\circ\ 16'\ 16'' \\
\odot\ \text{Par.} &= +\quad 7'' \\
\hline
a &= 37^\circ\ 16'\ 23'' \\
p &= 69^\circ\ 20'\ 4'' \\
l &= 46^\circ\ 30'\ 0'' \\
\hline
&\ 2)153^\circ\ 6'\ 27'' \\
S &= 76^\circ\ 33'\ 13'' \\
S - a &= 39^\circ\ 16'\ 50''
\end{aligned}
$$

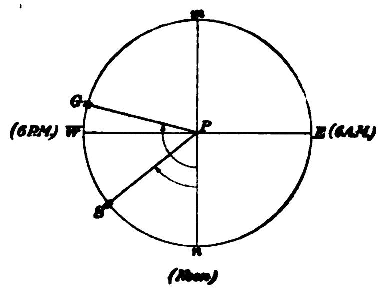


FIG. 5

$$
\begin{aligned}
\log \operatorname{cosec} 69^\circ\ 20'\ 4'' &= 0.02889 \\
\log \sec 46^\circ\ 30'\ 0'' &= 0.16219 \\
\log \cos 76^\circ\ 33'\ 13'' &= 9.36649 \\
\log \sin 39^\circ\ 16'\ 50'' &= 9.80148 \\
\hline
&\ 2)\ 19.35905 \\
\log \sin \tfrac{1}{2}\ \text{H. A.} &= 9.67952
\end{aligned}
$$

$$
\begin{aligned}
\text{L. App. T.} &= 3^h\ 48^m\ 30^s\ (\text{P. M. column}) \\
\text{Eq. of T.} &= +\ 10^m\ 27^s \\
\hline
\text{L. M. T., Jan. 17} &= 3^h\ 58^m\ 57^s\ \text{P. M.} \\
\text{G. M. T., Jan. 17} &= 7^h\ 29^m\ 30^s\ \text{P. M.}
\end{aligned}
\Bigg\}\ \text{Fig. 5}
$$

$$
\begin{aligned}
\text{Diff.} &= 3^h\ 30^m\ 33^s \\
\text{Long.} &= 52^\circ\ 38'\ 15''\ \text{W.} \quad \text{Ans.}
\end{aligned}
$$

9. Correction for Run.—The longitude found in the foregoing examples is that corresponding to the time of observation, while the latitude used in the calculation is generally that obtained by dead reckoning from some previous determination. This latitude, however, may be considerable in error, and should not be used unless the latitude by noon sight is lost. In practice, it is customary

to make the observation for the hour angle in the morning when the sun is on or near the prime vertical, and then to work out the longitude at noon, using the latitude then found corrected for the difference of latitude made during the interval between the time of observation and noon, the course and distance run being known. This procedure in working back the latitude is known as **correction for run, or working back.**

For instance, if the latitude found at noon is 40° 50′ N, and the course and distance run from the time of observation in the morning until noon is north 30 miles, the correct latitude at the time of observation was 40° 20′ N, and this is the latitude that should be used in calculating the longitude. Again, if the observation for the hour angle, or *time sight*, as it is usually called, is made in the afternoon, and the latitude at noon was 40° 50′ N, the course and distance run in the interval being, say, north 26 miles, it is evident that the latitude to be used in calculating the longitude is not 40° 50′ N, but 40° 50′ + 26′ N, or 41° 16′ N.

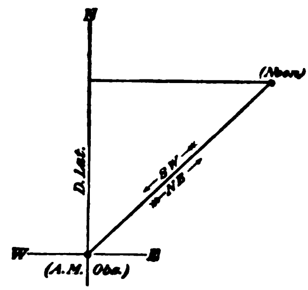


Fig. 6

Had the course and distance run in the former case been N E 30 miles (see Fig. 6), then the latitude at observation in the morning would have been obtained by entering the Traverse Tables with S W as the course and 30′ as the distance, and applying the difference of latitude thus found to the latitude in at noon.

10. Since the longitude computed is that corresponding to the ship's position at the time of observation, it is evident that the longitude in at noon is found by applying the difference of longitude corresponding to the course and distance run in the interval. In the following examples will be shown how the latitude is worked back from noon to an A. M. sight, and from noon to a P. M. sight; also, how the longitude at noon is found from A. M. and P. M. sights.

Example 1.—On November 27, 1899, in the forenoon, the observed altitude of the sun's lower limb was 37° 41′ 20″. Index error = + 5′ 25″. Height of eye = 21 feet. The Greenwich mean time, or chronometer time corrected at the instant of observation, was November 26, $13^h\ 45^m\ 45^s$. At noon, the latitude found by a meridian altitude was 23° 38.5′ N., the course and distance run from the time of observation until noon being E N E 30 miles. Required, the longitude at observation and at noon.

Solution.— G. M. T., Nov. 26 = $13^h\ 45^m\ 45^s$.

⊙ Decl., Nov. 27 = S 21° 9′ 12″
Corr. = − 4′ 38″
⊙ Corr. Decl. = S 21° 4′ 34″
90° 0′ 0″
P. D. = 111° 4′ 34″

Change in 1^h = 27.3″
× 10.2^h
278.46″
Corr. = 4′ 38″

Eq. of T., Nov. 27 = $12^m\ 15.4^s$
Corr. = + 8.5^s
Corr. Eq. of T. = $12^m\ 24^s$ (+)

Change in 1^h = 0.83^s
× 10.2^h
Corr. = 8.466^s

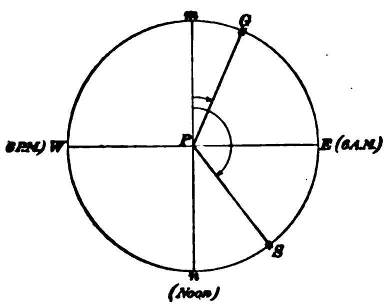


Fig. 7

Obs. Alt. ⊙ = 37° 41′ 20″
I. E. = + 5′ 25″
37° 46′ 45″
Dip = − 4′ 29″
37° 42′ 16″
⊙ S. D. = + 16′ 15″
37° 58′ 31″
Ref. = − 1′ 14″
37° 57′ 17″
⊙ Par. = + 7″
a = 37° 57′ 24″

Lat. at noon = 23° 38.5′ N
Traverse Tables, W S W, 30 mi. } D. Lat. = − 11.5′ S
Lat. at Obs. = 23° 27′ N

a =	37° 57′ 24″		
p =	111° 4′ 34″	log cosec =	0.03006
l =	23° 27′ 0″	log sec =	0.03744
	2)172° 28′ 58″		
S =	86° 14′ 29″	log cos =	8.81656
$S - a$ =	48° 17′ 5″	log sin =	9.87300
			2)18.75706
		log sin $\frac{1}{2}$ H. A. =	9.37853

$$\begin{array}{rl}
\text{L. App. T.} = & 10^h\ 9^m\ 20^s \text{ (A. M. column)} \\
\text{Eq. of T.} = & +\ 12^m\ 24^s \\
\hline
\text{L. M. T., Nov. 27} = & 9^h\ 56^m\ 56^s \text{ A. M.} \\
\text{G. M. T., Nov. 27} = & 1^h\ 45^m\ 45^s \text{ A. M.} \\
\hline
\text{Diff.} = & 8^h\ 11^m\ 11^s \\
\text{Long. at Obs.} = & 122^\circ\ 47'\ 45''\ \text{E. Ans.}
\end{array}
\left.\right\}\text{Fig. 7}$$

To find the longitude at noon, apply either middle-latitude or Mercator's sailing, two latitudes, the course, and the distance being known. Thus,

$$\begin{array}{rlrl}
\text{Lat. at noon} = & 23^\circ\ 38.5' & \text{M. P.} = & 1{,}451.3 \\
\text{Lat. at Obs.} = & 23^\circ\ 27' & \text{M. P.} = & 1{,}438.9 \\
\hline
& & \text{M. D. Lat.} = & 12.4
\end{array}$$

D. Long. = M. D. Lat. $\times$ tan C

$$\begin{array}{rlrl}
\log 12.4 = & 1.09342 & \text{Course} = & \text{E N E} = \text{N } 67^\circ\ 30'\ \text{E} \\
\log \tan 67^\circ\ 30' = & 0.38278 & \text{Dist.} = & 30 \text{ mi.} \\
\hline
\log \text{D. Long.} = & 1.47620 & & \\
\text{D. Long.} = & 29.9'\ \text{E} & &
\end{array}$$

$$\begin{array}{rl}
\text{Long. at Obs.} = & 122^\circ\ 47.7'\ \text{E} \\
\text{D. Long.} = & +\ \ 29.9'\ \text{E} \\
\hline
\text{Long. at noon} = & 123^\circ\ 17.6'\ \text{E. Ans.}
\end{array}$$

EXAMPLE 2.—In the afternoon of June 30, 1899, the observed altitude of the sun's lower limb was 54° 30′ 10″. Height of eye = 19 feet. Index error = + 2′ 30″. The chronometer time at the instant of observation was June 30, $3^h\ 38^m\ 22^s$, the error on Greenwich mean time being $2^m\ 15^s$ slow. The latitude determined by a meridian altitude at noon was 48° 11′ 12″ N, the course and distance run between noon and the time of observation being S 32° W 25 miles. Find the longitude at observation and at noon.

SOLUTION.—

$$\begin{array}{rl}
\text{Chron. June 30} = & 3^h\ 38^m\ 22^s \\
\text{Error (slow)} = & +\ \ 2^m\ 15^s \\
\hline
\text{G. M. T., June 30} = & 3^h\ 40^m\ 37^s
\end{array}$$

$$\begin{array}{rlrl}
\odot\ \text{Decl., June 30} = & \text{N } 23^\circ\ 11'\ \ 2.2'' & \text{Change in } 1^h = & 9.1'' \\
\text{Corr.} = & -\qquad 0'\ 33.7'' & & \times\ 3.7^h \\
\hline
\odot\ \text{Corr. Decl.} = & \text{N } 23^\circ\ 10'\ 28.5'' & \text{Corr.} = & 33.67'' \\
& \quad 90^\circ\ \ 0'\ \ \ 0'' & & \\
\hline
\text{P. D.} = & \quad 66^\circ\ 49'\ 31.5'' & &
\end{array}$$

$$\begin{array}{rlrl}
\text{Eq. of T., June 30} = & 3^m\ 21.7^s & \text{Change in } 1^h = & .49^s \\
\text{Corr.} = & +\ \ 1.8^s & & \times\ 3.7^h \\
\hline
\text{Corr. Eq. of T.} = & 3^m\ 23.5^s\ (+) & \text{Corr.} = & 1.813^s
\end{array}$$

Obs. Alt. $\underline{\odot}$ = 54° 30′ 10″
I. E. = + 2′ 30″
54° 32′ 40″
Dip = − 4′ 16″
54° 28′ 24″
$\odot$ S. D. = + 15′ 46″
54° 44′ 10″
Ref. = − 41″
54° 43′ 29″
$\odot$ Par. = + 5″
a = 54° 43′ 34″
p = 66° 49′ 32″ log cosec = 0.03654
l = 47° 50′ 0″ log sec = 0.17309
2)169° 23′ 6″
S = 84° 41′ 33″ log cos = 8.96614
$S - a$ = 29° 57′ 59″ log sin = 9.69853
2)18.87430
log sin $\frac{1}{2}$ H. A. = 9.43715

Entering Traverse Tables with S 32° W as course and 25 mi. as distance, gives D. Lat. 21.2′, and Dep. 13.2′.

Lat. at noon = 48° 11′ 12″ N
D. Lat. = 21′ 12″ S
Lat. at Obs. = 47° 50′ 0″ N

L. App. T. = $2^h\ 7^m\ 2^s$ (P. M. column)
Eq. of T. = + $3^m\ 23.5^s$
L. M. T., June 30 = $2^h\ 10^m\ 25.5^s$ P. M.
G. M. T., June 30 = $3^h\ 40^m\ 37^s$ P. M.
Diff. = $1^h\ 30^m\ 11.5^s$
Long. at Obs. = 22° 33′ W. Ans.

Now, by entering the Traverse Tables with the M. Lat. (48°) as course and the Dep. 13.2′ in a latitude column, opposite, in the distance column, will be found the corresponding D. Long., or 20′; and, as the course made good since noon was in the S W quadrant, this difference of longitude should be applied in the opposite direction. Thus,

Long. at Obs. = 22° 33′ W
D. Long. = 20′ E
Long. at noon = 22° 13′ W. Ans.

11. Under certain circumstances, those in charge of the navigation of a ship do not care to wait until noon to work out their observation for longitude, but are desirous of knowing the approximate position of the ship immediately after making the observations. In such cases, it is evident that the latitude by dead reckoning worked up from the

previous noon or from any other determination must be used. The longitude thus found may be very nearly correct, depending in the first place on the accuracy of the latitude used as well as on the accuracy used in measuring the altitudes. As a rule, however, the result should not be considered trustworthy unless the latitude used is correct or the bearing of the sun at time of sight was east, in which case, an error in latitude will have only a slight effect on the hour angle. The error in the longitude worked out immediately after the sight is made is readily ascertained when observations are subsequently taken at noon, and the longitude may then be reworked by using the new value of the latitude, corrected for run in the usual way.

LONGITUDE BY STAR OBSERVATIONS

(*Time Sight of a Star*)

12. Explanation.—The method of finding the longitude by means of a time sight of a star is practically the same as that used for the sun, the only difference being that instead of comparing the local mean time with the Greenwich mean time, *the local sidereal time is compared with the corresponding Greenwich sidereal time.* The difference between these two, expressed in angular measurement, is the required longitude.

13. Directions.—Measure a set of altitudes and note the corresponding chronometer times as usual. Reduce the Greenwich mean time into Greenwich sidereal time, according to *Nautical Astronomy*, Part 2. Find from the Nautical Almanac the star's right ascension and declination. Calculate the hour angle in exactly the same way as for the sun, but use only the P. M. column of the tables.

If the hour angle is *east* (or when the observed star is to the east of the observer's meridian), *subtract* it from the star's right ascension; if the hour angle is *west* (or the star west of the meridian), *add* it to the star's right ascension. The result will be the right ascension of the observer's meridian, or the local sidereal time (see *Nautical Astronomy*, Part 2).

The difference between this time and Greenwich sidereal time, reduced to degrees, minutes, etc., is the required longitude.

EXAMPLE.—On June 10, 1899, P. M., in latitude 40° 25′ S, the observed altitude of the star α Crusis when west of the meridian was 60° 21′ 40″. Index error = − 3′ 9″. Height of eye = 16 feet. At the instant of observation the ship's chronometer indicated $2^h\ 42^m\ 15^s$, June 10, its error on Greenwich mean time being $2^m\ 15^s$ fast. Find the longitude.

SOLUTION.—

Chron. =	$2^h\ 42^m\ 15^s$	Sid. time G. M. N. =	$5^h\ 14^m\ 29.6^s$
Error (fast) =	$-\quad 2^m\ 15^s$	Corr. for $2^h\ 40^m$ =	26.3^s
G. M. T., June 10 =	$2^h\ 40^m\ 0^s$	R. A. M. S. =	$5^h\ 14^m\ 55.9^s$
R. A. M. S. =	$+\ 5^h\ 14^m\ 56^s$		
G. Sid. T., June 10 =	$7^h\ 54^m\ 56^s$		

Obs. Alt. ✱ =	60° 21′ 40″	✱ Decl. =	S 62° 32′ 21″
I. E. =	− 3′ 9″		90° 0′ 0″
	60° 18′ 31″	✱ P. D. =	27° 27′ 39″
Dip =	− 3′ 55″		
	60° 14′ 36″	✱ R. A. =	$12^h\ 21^m\ 0^s$
Ref. =	− 33″		

a =	60° 14′ 3″		
p =	27° 27′ 39″	log cosec =	0.33616
l =	40° 25′ 0″	log sec =	0.11842
	2)128° 6′ 42″		
S =	64° 3′ 21″	log cos =	9.64097
$S - a$ =	3° 49′ 18″	log sin =	8.82381
			2)18.91936
		log sin $\frac{1}{2}$ H. A. =	9.45968

✱ H. A. =	$2^h\ 14^m$ W (P. M. column)
✱ R. A. =	$12^h\ 21^m$ (+)
L. Sid. T., June 10 =	$14^h\ 35^m\ 0^s$
G. Sid. T., June 10 =	$7^h\ 54^m\ 56^s$
Diff. =	$6^h\ 40^m\ 4^s$
Long. =	100° 1′ E. Ans.

14. In the foregoing example, if the local sidereal time found had been converted into corresponding local mean time, and the mean time thus obtained had been compared

with the Greenwich mean time as indicated by the chronometer, it is evident that the resulting longitude would have been precisely the same, as shown in the following:

$$\begin{array}{rl}
\text{L. Sid. T., June 10} = & 14^h\ 35^m\ 0^s \\
\text{R. A. M. S.} = & -\ 5^h\ 14^m\ 56^s \\
\hline
\text{L. M. T., June 10} = & 9^h\ 20^m\ 4^s \\
\text{G. M. T., June 10} = & 2^h\ 40^m\ 0^s \\
\hline
\text{Diff.} = & 6^h\ 40^m\ 4^s \\
\text{Long.} = & 100^\circ\ 1'\ \text{E. Ans.}
\end{array}$$

Example.—On October 18, 1899, at about $2^h\ 30^m$ A. M., the observed altitude of the star Sirius when east of the meridian was 53° 59′ 20″. Index error = − 3′ 57″. Height of eye = 22 feet. The time indicated by the chronometer was $11^h\ 1^m\ 43^s$, its error on Greenwich mean time being $2^m\ 16^s$ slow. Longitude, by dead reckoning = 50° E. Latitude, by star observation = 15° 14′ S. Find the longitude.

Solution.—First find the approximate Greenwich date. Thus,

$$\begin{array}{rl}
\text{Approx. L. M. T., Oct. 17} = & 14^h\ 30^m \\
\text{Long. (E) in time} = & 3^h\ 20^m \\
\hline
\text{Approx. G. D., Oct. 17} = & 11^h\ 10^m
\end{array}$$

$$\begin{array}{rl}
\text{Chron.} = & 11^h\ 1^m\ 43^s \\
\text{Error (slow)} = & +\ 2^m\ 16^s \\
\hline
\text{G. M. T., Oct. 17} = & 11^h\ 3^m\ 59^s \\
\text{R. A. M. S.} = & 13^h\ 44^m\ 54^s \\
\hline
\text{G. Sid. T., Oct. 18} = & 0^h\ 48^m\ 53^s
\end{array}
\qquad
\begin{array}{rl}
\text{Sid. T. G. M. N.} = & 13^h\ 43^m\ 5.2^s \\
\text{Corr. for } 11^h\ 4^m = & 1^m\ 49.1^s \\
\hline
\text{R. A. M. S.} = & 13^h\ 44^m\ 54.3^s
\end{array}$$

$$\begin{array}{rl}
\text{Obs. Alt. } * = & 53^\circ\ 59'\ 20'' \\
\text{I. E.} = & -\ 3'\ 57'' \\
\hline
 & 53^\circ\ 55'\ 23'' \\
\text{Dip} = & -\ 4'\ 36'' \\
\hline
 & 53^\circ\ 50'\ 47'' \\
\text{Ref.} = & -\ 0'\ 42''
\end{array}
\qquad
\begin{array}{rl}
* \text{ Decl.} = & \text{S } 16^\circ\ 34'\ 39'' \\
 & 90^\circ\ 0'\ 0'' \\
\hline
* \text{ P. D.} = & 73^\circ\ 25'\ 21'' \\
 & \\
* \text{ R. A.} = & 6^h\ 40^m\ 42^s
\end{array}$$

$$\begin{array}{rll}
a = & 53^\circ\ 50'\ 5'' & \\
p = & 73^\circ\ 25'\ 21'' & \log \text{cosec} = 0.01843 \\
l = & 15^\circ\ 14'\ 0'' & \log \sec = 0.01553 \\
\hline
2)\ & 142^\circ\ 29'\ 26'' & \\
S = & 71^\circ\ 14'\ 43'' & \log \cos = 9.50725 \\
S - a = & 17^\circ\ 24'\ 38'' & \log \sin = 9.47598 \\
\hline
 & & 2)\ 19.01719 \\
 & & \log \sin \tfrac{1}{2} \text{ H. A.} = 9.50859
\end{array}$$

$$
\begin{aligned}
\ast\ \text{H. A.} &= 2^h\ 30^m\ 32^s \text{ E (P. M. column)}\\
\ast\ \text{R. A.} &= 6^h\ 40^m\ 42^s\\
\hline
\text{L. Sid. T., Oct. 18} &= 4^h\ 10^m\ 10^s\\
\text{G. Sid. T., Oct. 18} &= 0^h\ 48^m\ 53^s\\
\hline
\text{Diff.} &= 3^h\ 21^m\ 17^s\\
\text{Long.} &= 50°\ 19.3' \text{ E. Ans.}
\end{aligned}
$$

15. Application of Method to Moon and Planets. This method of determining the longitude by a star is also applicable to the moon and planets. When using the moon for a time sight, the beginner should bear in mind that the latitude and the Greenwich mean time must be accurately known; if not, the longitude derived from such an observation cannot be depended on. Furthermore, in observing the moon, the greatest care should be exercised in measuring the altitudes. The moon is therefore not so desirable an object for time sights as a star or a planet.

16. Time Sight of a Planet.—In working a time sight of a planet, proceed exactly as with that of a star, remembering, however, to correct the planet's declination and right ascension for the Greenwich mean time, as shown in the example that follows.

EXAMPLE.—On May 19, 1899, at about $9^h\ 45^m$ P. M., the sextant altitude of Jupiter, observed for time sight, was 30° 5′ 20″. Index error = + 3′ 23″. Height of eye = 33 feet. Planet east of meridian. Chronometer reading at the instant of sight = $6^h\ 38^m\ 55^s$. Error on Greenwich mean time = $8^m\ 40^s$ slow. Latitude by account = 48° 20′ N. Estimated longitude = 138° 30′ W. Required, the correct longitude.

SOLUTION.—

$$
\begin{aligned}
\text{Approx. L. M. T., May 19} &= 9^h\ 45^m \text{ P. M.}\\
\text{Long. (W) in time} &= 9^h\ 14^m\\
\hline
\text{Approx. G. M. T., May 19} &= 18^h\ 59^m
\end{aligned}
$$

$$
\begin{aligned}
\text{Chron.} &= \ 6^h\ 38^m\ 55^s\\
\text{Error (slow)} &= +\ 8^m\ 40^s\\
\hline
&\ 6^h\ 47^m\ 35^s\\
&+12^h\ \ 0^m\ \ 0^s\\
\hline
\text{G. M. T., May 19} &= \ 18^h\ 47^m\ 35^s\\
\text{R. A. M. S.} &= \ 3^h\ 50^m\ 51^s\\
\hline
\text{G. Sid. T., May 19} &= \ 22^h\ 38^m\ 26^s
\end{aligned}
\qquad
\begin{aligned}
\text{Sid. T. G. M. N.} &= \ 3^h\ 47^m\ 45.3^s\\
\text{Corr. for } 18^h\ 48^m &= +\ 3^m\ \ 5.3^s\\
\hline
\text{R. A. M. S.} &= \ 3^h\ 50^m\ 50.6^s
\end{aligned}
$$

Decl. Jupiter =	S 10° 59′ 57.2″	R. A. Jupiter =	14^h 2^m 45.5^s
Corr. (4.82″ × 5.2^h) =	+ 25.1″	Corr. (.99^s × 5.2^h) =	+ 5.1^s
Corr. Decl. =	S 11° 0′ 22.3″	Corr. R. A. =	14^h 2^m 50.6^s
	90° 0′ 0″		
P. D. =	101° 0′ 22.3″		
Obs. Alt. Jupiter =	30° 5′ 20″		
I. E. =	+ 3′ 23″		
	30° 8′ 43″		
Dip =	− 5′ 38″		
	30° 3′ 5″		
Ref. =	− 1′ 38″		
a =	30° 1′ 27″		
p =	101° 0′ 22″	log cosec =	0.00806
l =	48° 20′ 0″	log sec =	0.17731
	2) 179° 21′ 49″		
S =	89° 40′ 54″	log cos =	7.74471
$S - a$ =	59° 39′ 27″	log sin =	9.93602
			2) 17.86610
		log sin ½ H. A. =	8.93305

H. A. Jupiter =	0^h 39^m 20^s
R. A. Jupiter =	14^h 2^m 51^s
L. Sid. T., May 19 =	13^h 23^m 31^s
G. Sid. T., May 19 =	22^h 38^m 26^s
Diff. =	9^h 14^m 55^s
Long. =	138° 43′ 45″ W. Ans.

17. As to time sights of stars and planets, the chief difficulty with such observations arises from the want of a well-defined horizon. The best time, therefore, for observing these bodies is either early in the morning or late in the evening. Bright, moonlight nights are also very favorable for such observations, because the horizon is then fairly distinct. The longitude computed from time sights taken of stars at night with full moonlight may be considered as quite reliable, provided the observer is sufficiently skilled in measuring a correct altitude and performing the process of computation without mistakes.

LONGITUDE BY SUNRISE AND SUNSET SIGHTS

18. Explanations and Directions.—In connection with time sights, a method is here described of determining approximately the longitude of a ship by what is known as **sunrise and sunset sights.** As its name implies, this method is used when the sun is on the horizon either at sunrise or at sunset. It will be noticed that the sextant is not used in this method. The chronometer only being noted at time of contact.

The order of procedure is as follows: When the sun's upper or lower limb comes into contact with the horizon, note the chronometer and correct its time for whatever error is attached to it. Then find from the Nautical Almanac the declination and the equation of time, and correct each for the Greenwich date. Find the polar distance as usual. To the polar distance add the latitude in, by dead reckoning, and from the sum subtract 21′ if the *lower* limb was observed; or 53′ if the *upper* limb was observed. Half the sum of the result is the quantity S in the formula for hour angles. By adding to S the 21′ or 53′ previously subtracted, the quantity $(S - a)$ is obtained, whence the hour angle is computed in the usual way.

EXAMPLE.—On August 16, 1899, at sunset, the chronometer indicated $8^h\ 37^m\ 26^s$ when the sun's lower edge, or limb, came into contact with the horizon. The chronometer's error on Greenwich mean time was $5^m\ 56^s$ fast. Latitude in, by dead reckoning = 48° 10′ N. Find the longitude.

SOLUTION.—

$$\begin{aligned} \text{Chron.} &= 8^h\ 37^m\ 26^s \\ \text{Error (fast)} &= -\quad 5^m\ 56^s \\ \hline \text{G. M. T., Aug. 16} &= 8^h\ 31^m\ 30^s \end{aligned}$$

Eq. of T., Aug. 16	$= 4^m\ 8.3^s$	Change in 1^h	$= 0.5^s$
Corr.	$= -\ 4.2^s$		$\times\ 8.5^h$
Corr. Eq. of T.	$= 4^m\ 4^s\ (+)$	Corr.	$= 4.25^s$
⊙ Decl., Aug. 16	= N 13° 44′ 19″	Change in 1^h	= 47.4″
Corr.	= − 6′ 43″		$\times\ 8.5^h$
Corr. Decl.	= N 13° 37′ 36″	Corr.	= 402.90″
		Or	= 6′ 43″

Decl. =	13° 37′ 36″		
	90° 0′ 0″		
P. D. =	76° 22′ 24″	log cosec =	0.01240
Lat. =	48° 10′ 0″	log sec =	0.17590
	124° 32′ 24″		
Constant = −	21′ 0″		
	2)124° 11′ 24″		
S =	62° 5′ 42″	log cos =	9.67026
Constant = +	21′ 0″		
$S - a$ =	62° 26′ 42″	log sin =	9.94771
			2)19.80627
		log sin ½ H. A. =	9.90313

L. App. T. =	7^h 5^m 6^s
Eq. of T. =	+ 4^m 4^s
L. M. T., Aug. 16 =	7^h 9^m 10^s P. M.
G. M. T., Aug. 16 =	8^h 31^m 30^s P. M.
Diff. =	1^h 22^m 20^s
Long. =	20° 35′ W. Ans.

19. Cautionary Remarks.—This method of determining the longitude by sunrise and sunset sights should be used only on occasions when fog and cloudy weather have prevented the navigator from getting time sights of the sun or stars. It is evident that refraction and unusual atmospheric conditions in general often render this method unreliable.

Before working out any sight for either latitude or longitude, blank forms for each method should be used with all data properly arranged for insertion of figures. Printed forms are, of course, the best, but if none are available written ones may be prepared from the various solutions appearing throughout this Course. By the use of such forms many data may be prepared in advance, and in general they will be conducive to accurate and systematic work.

EXAMPLES FOR PRACTICE

1. On March 20, 1899, in the afternoon, the observed altitude of the sun's upper limb was 16° 59′ 40″. Index error = − 4′ 9″. Height of eye = 27 feet. Latitude, by dead reckoning = 56° 20′ S. The correct Greenwich mean time at the instant of observation was, March 20, 8^h 18^m 49^s. Required, the longitude. Ans. Long. = 63° 42.2′ W

2. At about 3:25 P. M., September 29, 1899, when in latitude and longitude, by account, 48° 17′ N and 125° 10′ W, respectively, the measured altitude of the sun's lower limb was 18° 42′ 15″. At the instant of observation, the chronometer indicated $12^h\ 8^m\ 34^s$, its error on Greenwich mean time being $6^m\ 24^s$ fast. Index error = − 5′ 3″. Height of eye = 34 feet. Find the longitude.

Ans. Long. = 125° 20.1′ W

3. On May 1, 1899, at about 6:30 P. M., the observed altitude of the star Rigel (β Orionis), west of the meridian, was 25° 55′ 50″. Index error = − 4′ 42″. Height of eye = 32 feet. The chronometer at the instant of observation indicated $12^h\ 0^m\ 0^s$; its error on Greenwich mean time, January 11, was $24^m\ 54^s$ slow, and on March 2, $24^m\ 34^s$ slow. Longitude in, by dead reckoning = 91° E. Latitude of ship at observation = 18° 14′ N. Find the longitude.

Ans. Long. = 91° 30.2′ E

4. On September 1, 1899, in the forenoon, the observed altitude of the sun's upper limb was 34° 29′ 30″. Index error = − 3′ 45″. Height of eye = 23 feet. The chronometer, which was $4^m\ 16^s$ slow on Greenwich mean time, indicated at the instant of observation, August 31, $21^h\ 18^m\ 21^s$. From the time of taking the sight until noon, the course and distance run was N W ½ N 31 miles. The latitude, as determined at noon, was 44° 42′ N. Find the longitude at observation and at noon.

Ans. $\begin{cases}\text{Long. at Obs.} = 10° 15′ \text{ W} \\ \text{Long. at noon} = 10° 42.6′ \text{ W}\end{cases}$

5. In the morning of April 26, 1899, when the chronometer indicated April 25, $10^h\ 15^m\ 44^s$, the sextant altitude of the sun's lower limb was 59° 18′ 50″. At the time, the estimated position of the ship was 33½° N and 179° E, the error of the chronometer on Greenwich mean time being $5^m\ 12^s$ slow. Height of eye = 28 feet. Index error = − 4′ 11″. What was the correct longitude at the time of observation?

Ans. Long. = 178° 54′ 45″ E

6. On April 26, 1899, at about 3:35 P. M., when the chronometer indicated $15^h\ 34^m$, the altitude of the sun's lower limb was measured and found to be 36° 48′ 30″. The chronometer error was $7^m\ 13^s$ slow on Greenwich mean time. The correct latitude at time of sight was 34° 7′ N, the estimated longitude being 178° 30′ E. Height of eye = 24 feet. Index error = − 5′ 22″. Find the correct longitude at time of observation.

Ans. Long. = 178° 26′ 15″ E

7. On September 28, 1899, at about 6 P. M., the observed altitude of the star α Cygni was 68° 25′ 40″, east of the meridian. Index error = + 4′ 16″. Height of eye = 22 feet. The latitude of the ship, as determined by the polar star, was 50° 17′ N. Longitude in, by dead reckoning = 160° 20′ E. The time indicated by the chronometer was

$7^h\ 28^m\ 6^s$, its error on Greenwich mean time being $3^m\ 55^s$ fast. Required, the longitude. Ans. Long. = 160° 19.7′ E

8. On December 14, 1899, at noon, the position of the ship, as determined by dead reckoning, was latitude = 51° 25′ N and longitude = 11° 5′ 45″ W. The unfavorable weather conditions that prevailed throughout the day cleared away at dusk, and at about $4^h\ 45^m$ the observer was able to get a time sight of the star Vega (α Lyræ), west of the meridian, whose altitude then was found to be 49° 40′ 40″. Index error of instrument = − 4′ 19″. Height of eye = 19 feet. The chronometer at the instant of observation indicated $5^h\ 31^m\ 50^s$, its error on Greenwich mean time being $8^m\ 26^s$ fast. The course and distance run from noon until observation was S 88° E 56 miles. Required, the longitude. Ans. Long. = 9° 35′ W

AZIMUTH DETERMINATIONS

FINDING THE COMPASS ERROR AT SEA

20. Preliminary Remarks.—The methods of ascertaining the deviation of the compass by means of terrestrial objects, the magnetic bearings of which are known, have already been discussed at some length. It has been shown that the difference between the magnetic bearing of an object and its bearing by compass is the deviation for the particular point, or direction in which the ship is heading at the time of taking the bearing. At sea, however, and when out of sight of land, the utilization of terrestrial objects for determining the deviation of a compass is out of the question, and the navigator must then resort to methods by which the deviation of his compass may be found by the bearing of celestial objects. Of these methods, there are several, but only those in most common use will be considered here; namely, the *amplitude*, the *altitude-azimuth*, and the *time-azimuth methods.*

21. The principles of these methods are essentially the same as for the methods in which the bearings of terrestrial objects are used, the only difference being that in dealing with celestial objects the *true bearing* of the object is compared with its compass bearing. Hence, the result obtained

by taking their difference is not the *variation* of the compass, as it is sometimes erroneously termed, but the **total compass error,** or, in other words, the combined effect of *both variation and deviation.*

Since the variation of the compass for any particular part, or locality, of the sea is conveniently found on charts, it is evident that by allowing for this error, the required deviation is readily deduced. The change of magnetic variation is so inconsiderable as to be barely appreciable from year to year, and when once determined and registered for any place, it will, with slight modification, serve for a considerable period.

22. The true bearing of the celestial object is either calculated or obtained by inspection from tables especially prepared for this purpose, and the compass bearing is taken directly by the ship's compass.

AMPLITUDE OBSERVATIONS

23. Amplitude.—As previously explained, the *amplitude* of a celestial body is its angular distance measured along the horizon from the east or the west point at the time of its rising or its setting. Thus, in Fig. 8, if HH' represents the sea horizon, E the true east point, S the sun, and O the place of an observer, the angle EOS is the true amplitude. The amplitude is expressed east or west so many degrees north or south.

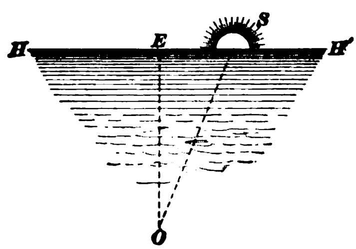


FIG. 8

Thus, when the amplitude is E 15° S, it means that the sun's center at rising is 15° south of the true east point; and when the amplitude is W 20° N, it means that the sun's center at setting is 20° north of the true west point of the horizon.

24. Amplitude Tables.—A complete set of tables giving the true amplitude for every half degree of declination and every degree of latitude from 10° to 77°, inclusive,

is incorporated in the Nautical Tables. In latitudes above 65°, the amplitude is given for every half degree. To use these tables for finding the true amplitude, it is necessary to know the declination and the latitude to the nearest half degree. The tables are then entered with the declination at the top and the latitude at the side, when under the former and directly opposite the latter is found the true amplitude, which is named *east* at rising, *west* at setting, and *north* if the declination is north or *south* if the declination is south. Thus, if the latitude in is 42° N and the declination of the sun is 21° S, the observation being taken at sunrise, the true amplitude is E 28.8° S. Again, if the latitude of the ship is 47° N and the declination is 13° 30′ N, the observation being taken at sunset, the true amplitude is W 20° N.

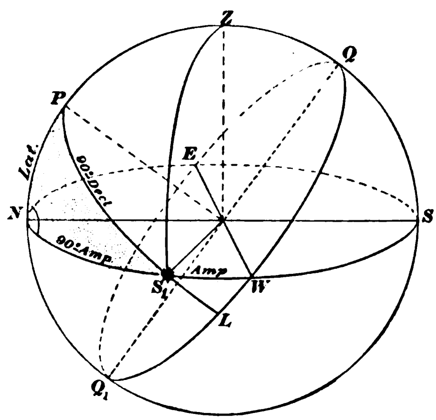


FIG. 9

25. Formula for Computing Amplitude.—When amplitude tables are not available, the amplitude may be computed by means of a formula derived as follows: In Fig. 9, $NESW$ represents the horizon, P the elevated pole, Z the observer's zenith, and S_1 the position of a celestial body on the horizon. WS_1 is then the amplitude, S_1L the declination, and QZ ($= NP$) the latitude of the observer. Applying Napier's rules to the right spherical triangle PNS_1, it is evident that

$$\cos(90° - \text{Decl.}) = \sin \text{Lat.} \times \sin(90° - \text{Amp.})$$
$$\cos(90° - \text{Decl.}) = \cos \text{Lat.} \times \cos(90° - \text{Amp.})$$
$$\sin \text{Decl.} = \cos \text{Lat.} \times \sin \text{Amp.}$$

Whence,

$$\sin \text{Amp.} = \frac{\sin \text{Decl.}}{\cos \text{Lat.}} = \sin \text{Decl.} \times \sec \text{Lat.}$$

26. Correction of Observed Amplitudes.—Observations for amplitude should be made when the sun's center appears to be on the horizon, or in the position shown in Fig. 8, either at sunrise or at sunset. To the amplitude thus found, a correction should be applied for the apparent displacement of the sun caused by refraction, dip, and parallax. This correction, which is found in the table on page 158 of the Nautical Tables, is applied to the right at rising and to the left at setting.

27. Directions for Observing.—From the foregoing explanation, the operation of finding the deviation of the compass by an amplitude observation of the sun may be stated as follows: Be ready at the compass a few minutes before the sun is about to rise or set. When the sun's center appears to be on the horizon, note its bearing and apply the correction. Correct the declination of the object for the Greenwich date and find the latitude in; also find beforehand by inspection of the chart, the variation of the locality. Calculate the true amplitude by the formula of Art. 25, or find it from the Amplitude Tables, and mark it E at the rising and W at the setting of the body, and toward N or S, according to the declination. Compare the true amplitude thus found, with the amplitude observed by compass. Draw a diagram (no matter how rough) representing the cardinal points, and from the center of this diagram lay off, respectively, the true amplitude and the compass bearing. The angle formed by these bearings will be the whole error of the compass, and is named *east* when the true amplitude falls to the right of the compass bearing, and *west* when it falls to the left. Then, in order to find the deviation, use the same diagram, but turn to the north point (which represents true north) and lay off from this point the whole compass error, east or west, as the case may be, and from the same point also lay off the variation.

The deviation is then, the difference between the total error and the variation if both have the same names, but their sum if of different names; and is named east when the compass north

falls to the right of the magnetic north, but west when the compass north falls to the left of the magnetic north.

The deviation thus found is the deviation for the point on which the ship is heading when the bearing is taken.

NOTE.—In the examples that follow, the given bearing is the corrected compass amplitude of the sun. In other words, the correction mentioned in Art. **26** has been applied.

EXAMPLE.—On December 1, 1899, at about $8^h\ 50^m$ P. M., the sun's bearing by the ship's compass was S $\frac{1}{2}$ E. Latitude in = 59° 3′ S. Longitude in = 32° 15′ W. The ship was heading N N W. The variation according to chart was 15° 30′ E. Required, the true amplitude and deviation for heading.

SOLUTION.—First find the Greenwich date and then the declination. Thus,

$$\begin{aligned} \text{L. App. T.} &= 8^h\ 50^m \text{ P. M.} \\ \text{Long. (W) in time} &= \underline{2^h\ \ 9^m} \\ \text{G. D., Dec. 1} &= 10^h\ 59^m \end{aligned}$$

$$\begin{aligned} \odot \text{ Decl., Dec. 1} &= \text{S } 21°\ 49'\ 38.6'' \qquad & \text{Change in } 1^h &= 23.26'' \\ \text{Corr.} &= + \quad \underline{4'\ 15.8''} & &\underline{\times\ 11^h} \\ \odot \text{ Corr. Decl.} &= \text{S } 21°\ 53'\ 54'' & &255.86'' \\ & & \text{Corr.} &= 4'\ 15.8'' \end{aligned}$$

Then compute the true amplitude according to the given formula:

$$\sin \text{Amp.} = \sin \text{Decl.} \times \sec \text{Lat.}$$

$$\begin{aligned} \log \sin 21°\ 53'\ 54'' &= 9.57165 \\ \log \sec 59°\ \ 3'\ \ 0'' &= \underline{0.28879} \\ \log \sin \text{Amp.} &= 9.86044 \\ \text{True Amp.} &= \text{W } 46°\ 29'\ \text{S.} \quad \text{Ans.} \\ \text{Comp. bearing S } \tfrac{1}{2} \text{ E} &= \underline{\text{W } 95°\ 37'\ \text{S}} \\ \text{Total error} &= \quad 49°\ \ 8'\ \text{E} \\ \text{Variation} &= \quad \underline{15°\ 30'\ \text{E}} \\ \text{Dev. for N N W} &= \quad 33°\ 38'\ \text{E.} \quad \text{Ans.} \end{aligned}$$

28. Amplitude Diagrams.—The graphic solution of the preceding example is as follows: In Fig. 10, where S, W, N, E represent the cardinal points, lay off from the center O the true amplitude $O S_1$ (= W 46° 29′ S) and the compass bearing $O B$ (= W 95° 37′ S). The difference between these bearings, or the angle $S_1 O B$ (= 49° 8′), will be the *total* error of the compass, and is named *east* because

the true amplitude lies to the *right* of the compass bearing. To find the deviation, use the same diagram but turn to the point *N*, which represents the true north. Lay off from *N* the total compass error 49° 8′ E, and also lay off from the same point the variation of the locality 15° 30′ E. The required deviation is then the difference between the error and the variation, and is named *east*, because the compass north falls to the *right* of the magnetic north.

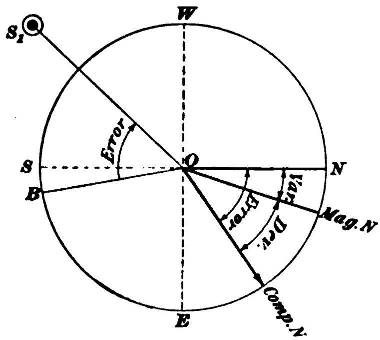


FIG. 10

A sketch, or diagram, used in the manner shown will be of great assistance in plotting the different bearings and in naming correctly the required deviation.

EXAMPLE 1.—The bearing, by compass, of the sun at rising on June 10, 1899, was E N E. The ship was in latitude 55° 30′ N and longitude 46° 48′ W, heading W S W. The correct Greenwich mean time at the instant of taking the bearing was June 9, $19^h\ 9^m$. Find the true amplitude and the deviation for the heading, the variation of the locality being 35° 45′ W.

SOLUTION.— G. D., June 9 = $19^h\ 9^m$

⊙ Decl., June 10 =	N 23° 1′ 28.4″	Change in 1″ =	11.45″
Corr. = –	55.2″		× 4.8^h
⊙ Corr. Decl. =	N 23° 0′ 33″	Corr. =	55.160″

sin Amp. = sin Decl. × sec Lat.

log sin 23° 0′ 33″ = 9.59203
log sec 55° 30′ 0″ = 0.24687

log sin Amp. = 9.83890

True Amp. = E 43° 39′ N. Ans.
Comp. bearing E N E = E 22° 30′ N

Total error = 21° 9′ W
Variation = 35° 45′ W

Dev. for W S W = 14° 36′ E. Ans.

In Fig. 11, the error of the compass is the angle $B O S_1$ and is *westerly*, since the true amplitude lies to the *left* of the compass bearing. The error and the variation laid off, respectively, from the true north will produce an *easterly* deviation, because the compass north is to the right of the magnetic north.

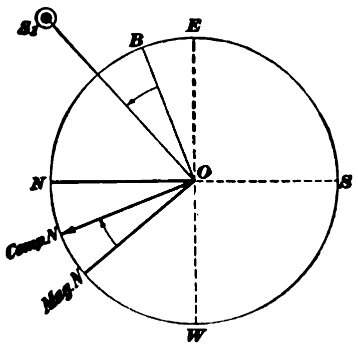


Fig. 11

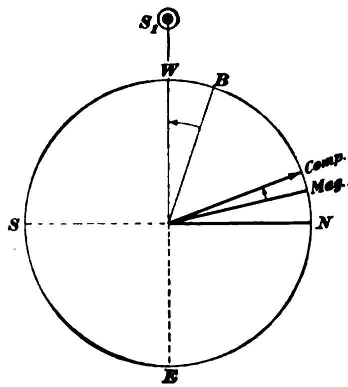


Fig. 12

Example 2.—At sunset, March 20, 1899, at about 6^h 6^m, local apparent time, the bearing of the sun by compass was found to be N 64° 30′ W, the ship heading E by S. Latitude in = 22° 30′ N. Longitude in = 23° W. Variation of compass by chart = 18° 15′ W. Find the deviation for heading of ship.

Solution.— L. App. T. = 6^h 6^m
Long. (W) in time = 1^h 32^m
G. D., Mar. 20 = 7^h 38^m

☉ Decl., Mar. 20 = S 0° 7′ 32″ Change in 1^h = 59.24″
Corr. for 7.6^h = − 7′ 32″ × 7.63^h
☉ Corr. Decl. = 0° 0′ 0″ 452.0012″
Corr. = 7′ 32″

In this case the declination of the sun is 0°, and it therefore sets true west. Hence,

True Amp. = west = 0° 0′
Comp. bearing N 64° 30′ W = W 25° 30′ N

Total error = 25° 30′ W
Variation = 18° 15′ W } Fig. 12

Dev. for E by S = 7° 15′ W. Ans.

The deviation in this case is westerly, because the compass north falls to the left of the magnetic north, as shown in Fig. 12.

29. True Amplitude by Inspection.—In practice at sea, instead of calculating the true amplitude, it is more conveniently found by inspection directly from the Amplitude Tables (pages 153 to 157 of the Nautical Tables). Usually, the tables are entered with the nearest whole or half degree of the latitude and declination given, which is sufficiently accurate for all practical purposes. This renders the whole operation comparatively simple, as is shown in the examples that follow.

EXAMPLE 1.—On November 27, 1899, at sunset, the compass amplitude, or bearing, of the sun was S 64° W. Heading of ship at time of observation = N W by N. Variation of locality = 6.5° E. Latitude = 20° N. Find the deviation.

SOLUTION.—Sun's Decl., Nov. 27, 1899 = S 21° 9′ or 21° S.

Obs. Comp. Amp.	=	S 64° W	
Or	=	W 26° S	
Corr. (to the left)	=	.3°	(Page 158, N. T.)
Corr. Comp. Amp.	=	W 26.3° S	
Decl. 21°, Lat. 20° } True Amp.	=	W 22.4° S	
Total error	=	3.9° E	
Variation	=	6.5° E	
Dev. for N W by N	=	2.6° W.	Ans.

In this example, it should be noted that the total error is easterly, because the true amplitude falls to the right of compass bearing; and the deviation is westerly, since compass north falls to the left of the magnetic north, as shown in Fig. 13.

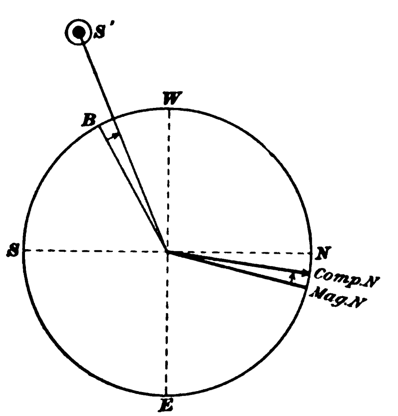


FIG. 13

EXAMPLE 2.—On May 20, 1899, at sunset, the bearing by compass of the sun's center was N W by W. Latitude in = 42° N. Find the deviation for heading of ship W by S, assuming the variation by chart to be 12.7° W.

SOLUTION.—Sun's Decl., May 20, 1899 = N 19° 59′ or 20°.

Obs. Comp. Amp. = N W by W	=	N 56.2° W
Or	=	W 33.8° N
Corr. (to the left)	−	.7°
Corr. Comp. Amp.	=	W 33.1° N
Decl. 20°, Lat. 42° } True Amp.	=	W 27.4° N
Total error	=	5.7° W
Variation	=	12.7° W
Dev. for W by S	=	7° E. Ans.

In this case, the total error is westerly, since the true amplitude falls to the left of the compass bearing (see Fig. 14); and the resulting deviation is easterly, because compass north falls to the right of the magnetic north.

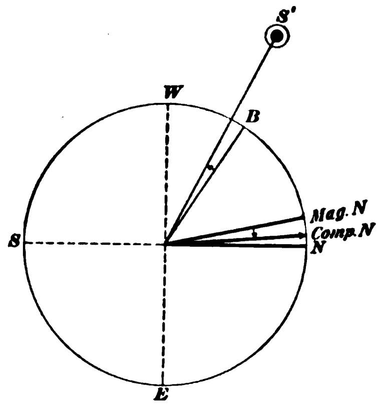


FIG. 14

30. Remarks on Amplitudes.—From the foregoing, it is evident that by this simple method the total error and deviation of the compass may be conveniently found any clear morning or evening, at rising or setting of the sun. By applying the method to stars, the error of the compass may be found at almost any time during a clear night. In the case of stars, however, only those of the first magnitude should be used; do not observe amplitudes of stars that are not actually identified. The moon should not be used for an amplitude, because the horizontal parallax depresses her center about two diameters while the effect of refraction causes it to rise only one diameter, thus rendering her amplitude untrustworthy. At every observation for amplitude, it is important that the ship's head according to the compass, by which the bearing is taken, should be noted. The deviation thus found applies only to the compass used in taking the bearing, and

is the deviation for that point on which the ship is heading at the instant of taking the bearing.

31. The result by amplitudes is most satisfactory in low latitudes, because there the direction of motion of any celestial body, whether rising or setting, is nearly vertical, and consequently a small change in altitude has no appreciable effect on the bearing. In high latitudes these conditions are changed; there, a small difference in the altitude causes a considerable difference in the bearing, because the setting and rising of a body takes place very obliquely to the horizon, especially when the declination of the body is of an opposite name to the latitude. Near the geographical poles, for instance, an observer would see the stars moving in paths nearly parallel with the horizon; a change of a few degrees in the altitude at those places would correspond to a large number of degrees in the bearing.

32. To Find the Time of Sunrise and Sunset.—In connection with amplitudes, it may be convenient and sometimes necessary to know beforehand the time of the rising and setting of the celestial body to be observed, so as to be on hand at the proper moment and thus save much valuable time in watching for such events. For this purpose, the table of Rising and Setting of a Celestial Body (found on pages 179 and 180 of the Nautical Tables), extending from latitude 10° to 75° N and S, may be used. The data to be known are the latitude in, and the declination of the body to be observed, to the nearest degree only. The method of using this table to find the time of the rising and setting of the sun is explained in the next article.

33. Directions.—Enter the table with the sun's declination at the top and the latitude in the side column; then, under the former and opposite the latter will be found the time of the sun's *setting* if the latitude and declination are of the *same* name, but the time of *rising* if they are of *different* names. The time of rising subtracted from 12 hours

will give the time of setting, or the time of setting subtracted from 12 hours will give the time of rising. The time of rising multiplied by 2 will give the length of the night, and the time of setting multiplied by 2 will give the length of the day.

EXAMPLE.—Find the time of sunrise and sunset December 12, 1900, in latitude 35° N, the sun's declination being 23° S; also, find the length of night and of day.

SOLUTION.—Entering the table, in the column below 23° declination and opposite 35° latitude will be found $7^h\ 9^m$. The latitude and the declination being of different names, $7^h\ 9^m$ is the time of rising. Ans.

For the time of setting, subtract the time of rising from 12 hours. Thus,

$$12^h - 7^h\ 9^m = 4^h\ 51^m. \text{ Ans.}$$

For the length of the night, the former is doubled, and for the length of the day, the latter is doubled. Thus,

$$\begin{array}{r} 7^h\ 9^m \\ \times 2 \\ \hline \end{array} \qquad\qquad \begin{array}{r} 4^h\ 51^m \\ \times 2 \\ \hline \end{array}$$

Length of night $= 14^h\ 18^m$. Ans. Length of day $= 9^h\ 42^m$. Ans.

The numbers in this table were calculated for the moment that the sun's center appears in the true horizon. Allowance should therefore be made for dip, parallax, and refraction, the combined effect of which tends to elevate the sun about half a degree or more above its true place when near the horizon.

ALTITUDE-AZIMUTH METHOD

34. Explanation.—According to a previous definition, the *true azimuth* of a celestial body is the arc of the horizon intercepted between the north or the south point and the vertical passing through the center of the body; or, the angle at the zenith between the observer's meridian and the vertical. Thus, in Fig. 15, the azimuth of the body S_1 is the arc $S m$ of the horizon $N E S W$; or, the angle at Z subtended by the meridian $S Z N$ and the vertical $Z S_1 m$ that passes through the body S_1. The *compass azimuth*, or the azimuth observed by the ship's compass, is measured in the same manner and is reckoned from north or south, so many degrees east or west.

35. Altitude-Azimuth Formula.—In the triangle $S_1 Z P$, Fig. 15, the three sides are known. $S_1 Z$ is the complement of the altitude, $Z P$ the complement of the

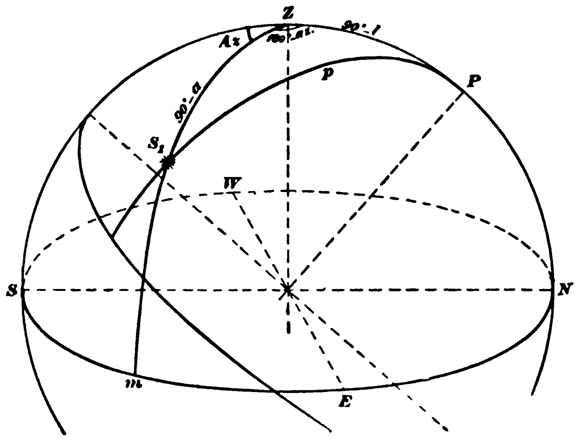


FIG. 15

latitude, and $S_1 P$ the polar distance. Hence, to find the angle SZP (= 180° − azimuth), the general formula

$$\cos A = \frac{\cos a - \cos b \cos c}{\sin b \sin c}$$

is used. When applied to the figure, this formula will appear as follows:

$$\cos(180° - \text{Az.}) = \frac{\cos p - \cos(90° - l)\cos(90° - a)}{\sin(90° - l)\sin(90° - a)},$$

in which p = polar distance;
l = latitude;
a = altitude.

Transformed for logarithmic use by the usual process, the formula becomes

$$\sin^2 \tfrac{1}{2}\text{Az.} = \frac{\cos S \cos(S - p)}{\cos l \cos a},$$

in which $S = \frac{1}{2}(a + l + p)$

Whence,

$$\sin \tfrac{1}{2}\text{Az.} = \sqrt{\cos S \cos(S - p) \sec a \sec l},$$

which is the formula used for computing the azimuth when the latitude of the observer, the altitude, and the declination of the observed object are known.

36. Directions.—The order of procedure for observing an altitude azimuth is as follows: Measure the altitude of the selected body and note the time shown by the chronometer at the instant of observation. At the same instant, the bearing of the object and the heading of the ship by the same compass should be noted by a second observer. Find the Greenwich date. Correct the declination of the object for the Greenwich date and find the polar distance. Reduce the observed altitude to true by applying the usual corrections. Then calculate the azimuth by the formula of the preceding article. The azimuth thus found should be reckoned from *north* when the latitude is south, and from *south* when the latitude is north, and toward *east* or *west*, according as it is A. M. or P. M. at ship.

To find the deviation, proceed similarly as in the case of amplitudes. Draw a figure and lay off the true azimuth and the compass bearing, and find the whole error. Then, using the same diagram, apply the total error to true north and lay off, respectively, the compass and the magnetic north.

EXAMPLE 1.—On December 17, 1899, A. M., while a ship was heading S W, the observed altitude of the sun's lower limb was 20° 29′ 30″. Index error = + 4′ 40″. Height of eye = 21 feet. At the instant of measuring the altitude, the sun's bearing by the ship's compass was S by W ½ W, and the corrected Greenwich time was December 17, $2^h\ 3^m$. Latitude in = 41° 22′ N. Required, the true azimuth and the deviation, assuming the variation of locality to be 18° W.

SOLUTION.—Proceed according to directions. Thus,

G. D., Dec. 17 =	$2^h\ 3^m\ 0^s$		
⊙ Decl., Dec. 17 =	S 23° 22′ 15″	Change in 1^h =	5.34″
Corr. =	+ 11″		$\times\ 2^h$
⊙ Corr. Decl. =	S 23° 22′ 26″	Corr. =	10.68″
	90° 0′ 0″		
P. D. =	113° 22′ 26″		

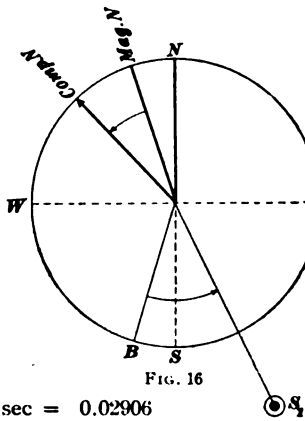


Fig. 16

Obs. Alt. $\underline{\odot}$ =	20° 29′ 30″		
I. E. =	+ 4′ 40″		
	20° 34′ 10″		
Dip =	− 4′ 29″		
	20° 29′ 41″		
$\odot$ S. D. =	+ 16′ 17″		
	20° 45′ 58″		
Ref. =	− 2′ 31″		
	20° 43′ 27″		
$\odot$ Par. =	+ 0′ 8″		
a =	20° 43′ 35″	log sec =	0.02906
p =	113° 22′ 26″		
l =	41° 22′ 0″	log sec =	0.12465
	2)175° 28′ 1″		
S =	87° 44′ 0″	log cos =	8.59715
$p - S$ =	25° 38′ 26″	log cos =	9.95497
			2)18.70583
		log sin $\frac{1}{2}$ azimuth =	9.35291
		$\frac{1}{2}$ azimuth =	13° 1.5′
		True azimuth =	S 26° 3′ E. Ans.

In this case, since the latitude is north and the observation is made in the forenoon, the azimuth is named *south* and *east*. To find the deviation for heading, proceed as usual. Thus,

True azimuth =	S 26° 3′ E		
Comp. bearing =	S 16° 52.5′ W (= S by W $\frac{1}{2}$ W)		
Total error =	42° 56′ W.	Ans.	Fig. 16
Variation =	18° 0′ W		
Dev. for S W =	24° 56′ W.	Ans.	

Example 2.—On December 10, 1899, at $2^h\ 12^m\ 36^s$ p. m., local mean time, the observed altitude of the sun's lower limb was 34° 54′ 20″. Index error = − 3′ 44″. Height of eye = 28 feet. The sun's bearing by compass at the instant of observation was S 30° W. The ship was heading W S W. Latitude in = 20° 15′ N. Longitude in = 161° 15′ W. Variation by chart = 20° E. Find the true azimuth and the deviation for heading.

Solution.—

L. M. T., Dec. 10 =	$2^h\ 12^m\ 36^s$
Long. (W) in time =	$10^h\ 45^m\ 0^s$
G. D., Dec. 10 =	$12^h\ 57^m\ 36^s$

☉ Decl., Dec. 11 =	S 23° 1′ 5″	Change in 1^h =	12.27″
Corr. =	− 2′ 15″		× 11^h
Corr. Decl. =	22° 58′ 50″		134.97″
	90° 0′ 0″	Corr. =	2′ 14.9″
P. D. =	112° 58′ 50″		

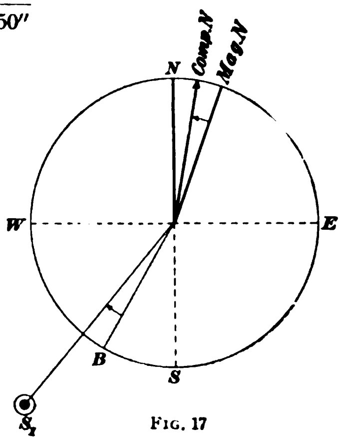


FIG. 17

Obs. Alt. ☉ =	34° 54′ 20″		
I. E. =	− 3′ 44″		
	34° 50′ 36″		
Dip =	− 5′ 11″		
	34° 45′ 25″		
☉ S. D. =	+ 16′ 17″		
	35° 1′ 42″		
Ref. =	− 1′ 22″		
	35° 0′ 20″		
☉ Par. =	+ 0′ 7″		
a =	35° 0′ 27″	log sec =	0.08667
p =	112° 58′ 50″		
l =	20° 15′ 0″	log sec =	0.02771
	2) 168° 14′ 17″		
S =	84° 7′ 8″	log cos =	9.01074
$p - S$ =	28° 51′ 42″	log cos =	9.94233
			2) 19.06745
		log sin $\frac{1}{2}$ azimuth =	9.53372
		$\frac{1}{2}$ azimuth =	19° 59′

True azimuth =	S 39° 58′ W.	Ans.
Comp. bearing =	S 30° 0′ W	
Total error =	9° 58′ E	(Fig. 17)
Variation =	20° 0′ E	
Dev. for W S W =	10° 2′ W.	Ans.

37. Simultaneous Observation for Azimuth and Hour Angle.—It should be observed that in the altitude-azimuth method exactly the same quantities are used as in the computation for hour angles in longitude problems; namely, *latitude*, *altitude*, and *polar distance*. In practice, it is therefore customary and very convenient to calculate the

azimuth at the same time as the hour angle. The compass bearing, or compass azimuth, being taken at the same time as the observation for hour angle, the same altitude may be used in determining the longitude, the true azimuth, and the deviation. Examples showing hour angle and azimuth worked out together will be given in *Sumner's Method.*

38. The altitude-azimuth method is applicable to any celestial body. As a rule, the object selected should be relatively low in altitude (from 20° to 40°). The compass bearing is then more readily taken and the conditions in general are more favorable for a reliable azimuth.

TIME-AZIMUTH METHOD

39. Explanation.—When the horizon is obscured so that altitudes cannot be taken, the **time-azimuth method** may be used for finding the true azimuth and the error of the compass. The method consists in taking the bearing of

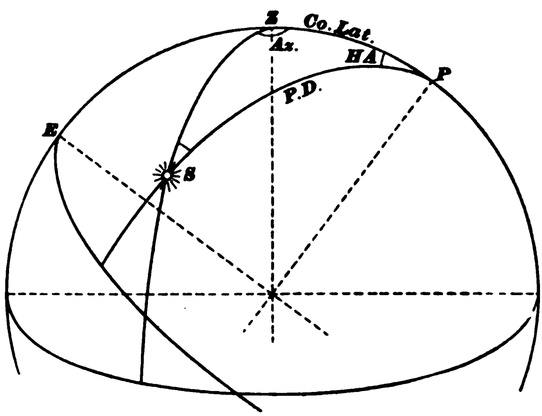


FIG. 18

a celestial object by compass, at the same instant noting the time by the chronometer, and from these data calculating the true azimuth by a formula derived as follows:

In the spherical triangle ZPS, Fig. 18, the colatitude ZP, the polar distance PS, and the hour angle ZPS are known,

while the altitude and the zenith distance SZ are unknown. To find the angle at Z, representing the azimuth, Napier's analogies are applied, the case being to find the angles at S and Z, two sides and the included angle being known. Thus,

$$\tan \tfrac{1}{2}(A + B) = \frac{\cos \tfrac{1}{2}(a - b)}{\cos \tfrac{1}{2}(a + b)} \cot \tfrac{1}{2} C$$

and

$$\tan \tfrac{1}{2}(A - B) = \frac{\sin \tfrac{1}{2}(a - b)}{\sin \tfrac{1}{2}(a + b)} \cot \tfrac{1}{2} C$$

Substituting in these formulas the angles Z and S, Fig. 18, for A and B, and likewise the corresponding sides and third angle for those of the figure,

$$\tan \tfrac{1}{2}(Z + S) = \frac{\cos \tfrac{1}{2}(\text{P. D.} - \text{Colat.})}{\cos \tfrac{1}{2}(\text{P. D.} + \text{Colat.})} \cot \tfrac{1}{2} \text{H. A.}$$

and

$$\tan \tfrac{1}{2}(Z - S) = \frac{\sin \tfrac{1}{2}(\text{P. D.} - \text{Colat.})}{\sin \tfrac{1}{2}(\text{P. D.} + \text{Colat.})} \cot \tfrac{1}{2} \text{H. A.}$$

The sum of these angles is the *greater* of the two angles Z and S, and the difference is the smaller angle. Since the greater angle is opposite the greater side, the azimuth Z is the greater angle when the polar distance is greater than the colatitude; and the smaller angle, when the polar distance is less than the colatitude. Furthermore, the angle Z is either the azimuth or the supplement of the azimuth, depending on the point of the horizon from which it is reckoned.

40. Directions.—When making observation for the time-azimuth method, proceed as follows: Take several bearings in quick succession and note the chronometer (or watch) at each. Use the mean of the bearings as the compass bearing, and the mean of the times as the chronometer time. Find the Greenwich date, correct the declination for this date, and obtain the polar distance. From the Greenwich mean time, find the hour angle of the observed body by applying the longitude in time and the equation of time. If the object is the sun, its hour angle is equal to the local apparent time; if any other object, the difference between the right ascension of the observer's meridian and the right ascension of the object is the hour angle of the object.

Having found the hour angle, reduce it to degrees and minutes of arc, and find also the colatitude (= 90° − latitude). Then, having the data required, calculate the azimuth according to the formulas given in the preceding article, and name it N in north latitude, S in south latitude, and E or W, according to whether the observation is made in the forenoon or in the afternoon. The azimuth being found, draw a figure and find the compass error and deviation as usual.

EXAMPLE.—On December 3, 1899, A. M., the bearing of the sun's center by the standard compass was S 44° 30′ E, the ship steering E by N. The Greenwich date corresponding to the instant of taking the bearing was December 3, $2^h\ 32^m\ 37^s$. Latitude in = 30° 25′ N. Longitude in = 80° 32′ W. Variation by chart = 7° 15′ W. Find the true azimuth and the deviation of the compass.

SOLUTION.—Proceed according to the foregoing directions. Thus,

$$
\begin{aligned}
\text{G. D., Dec. 3} &= 2^h\ 32^m\ 37^s \\
\text{Long. (W) in time} &= 5^h\ 22^m\ 8^s \\
\hline
\text{L. M. T., Dec. 2} &= 21^h\ 10^m\ 29^s \\
\text{Eq. of T.} &= +\ 10^m\ 1^s \\
\hline
\text{L. App. T.} &= 21^h\ 20^m\ 30^s \\
\text{H. A.} &= 2^h\ 39^m\ 30^s\ E \\
\tfrac{1}{2}\ \text{H. A.} &= 1^h\ 19^m\ 45^s = 19^\circ\ 56'\ 15''
\end{aligned}
$$

$$\text{Eq. of T., Dec. 3 (corrected)} = 10^m\ 1^s\ (+)$$

$$
\begin{array}{rl}
\odot\ \text{Decl., Dec. 3} = & S\ 22^\circ\ 7'\ 28.3'' \\
\text{Corr.} = & +\qquad 52.5'' \\
\hline
\odot\ \text{Corr. Decl.} = & 22^\circ\ 8'\ 21'' \\
 & 90^\circ\ 0'\ 0'' \\
\hline
\text{P. D.} = & 112^\circ\ 8'\ 21''
\end{array}
\qquad
\begin{array}{r}
\text{Change in } 1^h = 21'' \\
\times\ 2.5^h \\
\hline
\text{Corr.} = 52.5''
\end{array}
$$

$$
\begin{array}{rl}
 & 90^\circ\ 0' \\
\text{Lat.} = & 30^\circ\ 25' \\
\hline
\text{Colat.} = & 59^\circ\ 35'
\end{array}
\qquad
\begin{array}{rl}
\text{P. D.} - \text{Colat.} = & 52^\circ\ 33' \\
\text{P. D.} + \text{Colat.} = & 171^\circ\ 43' \\
\tfrac{1}{2}\ (\text{P. D.} - \text{Colat.}) = & 26^\circ\ 16' \\
\tfrac{1}{2}\ (\text{P. D.} + \text{Colat.}) = & 85^\circ\ 51'
\end{array}
$$

These data having been found, calculate the azimuth according to the given formula. Thus,

$$
\begin{array}{rlrl}
\tfrac{1}{2}\ (\text{P. D.} - \text{Colat.}) = 26^\circ\ 16'\ \cos = & 9.95267 & \sin = & 9.64596 \\
\tfrac{1}{2}\ (\text{P. D.} + \text{Colat.}) = 85^\circ\ 51'\ \sec = & 1.14045 & \text{cosec} = & 0.00114 \\
\tfrac{1}{2}\ \text{H. A.} = 19^\circ\ 56'\ \cot = & 0.44051 & \cot = & 0.44051 \\
\hline
\log \tan \tfrac{1}{2}\ (Z + S) = & 11.53363 & \tan \tfrac{1}{2} (Z - S) = & 10.08761 \\
\tfrac{1}{2}\ (Z + S) = & 88^\circ\ 19' & \tfrac{1}{2} (Z - S) = & 50^\circ\ 44'
\end{array}
$$

In this case, since the polar distance is greater than the colatitude, the sum of the angles is equal to the required azimuth. Thus,

$$\begin{array}{rl}
\frac{1}{2}(Z+S) = & 88^\circ\ 19' \\
\frac{1}{2}(Z-S) = & 50^\circ\ 44' \\
\hline
\text{True azimuth} = & \text{N } 139^\circ\ 3' \text{ E. Ans.} \\
\text{Comp. bearing} = & \text{N } 135^\circ\ 30' \text{ E } (= \text{S } 44^\circ\ 30' \text{ E}) \\
\hline
\text{Total error} = & 3^\circ\ 33' \text{ E} \\
\text{Variation} = & 7^\circ\ 15' \text{ W} \\
\hline
\text{Dev. for E by N} = & 10^\circ\ 48' \text{ E. Ans.}
\end{array} \left.\right\} \text{Fig. 19}$$

41. Azimuth Tables.—In actual practice, the true azimuth is not always computed, but is taken directly from the Azimuth Tables. These tables contain the azimuth, or true bearing, of the sun or other object corresponding to different values of latitude, declination, and apparent time. Among them may be mentioned the following:

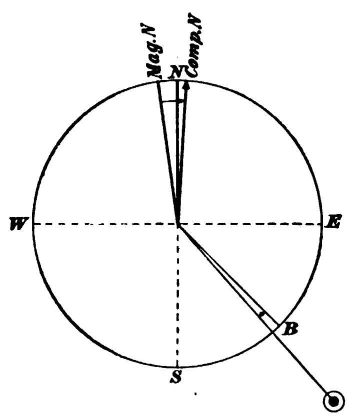


Fig. 19

"Sun's True Bearing or Azimuth Tables Computed for Intervals of 4 Minutes Between the Parallels of Latitude 30° and 60°, Inclusive." By John Burdwood.

"Sun's True Bearing or Azimuth Tables Computed for Intervals of 4 Minutes Between the Parallels of Latitude 30° N and 30° S, With Variation Chart and Instructions." By Capt. John E. Davis.

"Stellar Azimuth Tables, in Which Are Given the True Bearings of Certain Principal Stars for Every Night During the Year From the Equator to Latitudes 62° N and S." By W. C. Croudace.

"Tables des Azimuts du Soleil correspondants à l'heure vraie du bord entre les Paralleles 61° sud et 61° nord." By F. Labrosse.

The Azimuth Tables used in the United States Naval Service and Merchant Marine are prepared and published by

the United States Hydrographic Office. These tables may be obtained at any nautical warehouse or supply store, or directly from the Hydrographic Office, Washington, District of Columbia, for $1. The azimuths are given in intervals of 10 minutes between sunrise and sunset, and for parallels of latitude between 61° N and 61° S, inclusive, and are computed by the time-azimuth formula.

These Azimuth Tables are divided into three sections. The first section consists of a single table giving the true azimuths corresponding to latitude 0°. The second section contains the azimuths corresponding to each degree of latitude between 1° and 61°, inclusive, when the latitude and declination are of the same name. The third section contains the azimuths for the same degrees of latitude when the latitude and declination are of different names. A specimen page from the second section is shown on page 45.

42. On each page, at the top of each column of azimuths, are given the 4 days of the year on which the sun's declination corresponds approximately with the declination given for that particular column of azimuths. By this arrangement, when only an approximate result is required, the observer may use the nearest day instead of the declination, and thereby eliminate the use of the Nautical Almanac. In the examples that follow, however, the declination for the given date should be taken from the abridgment of the Nautical Almanac accompanying *Nautical Astronomy*, Part 2, and entered to the nearest degree at the top of the Azimuth Table.

Under the columns of true azimuths, in each table, will be found an extra table containing the times of sunrise and sunset and the corresponding azimuths (= 90° − amplitude); and below these tables are given the rules for naming the azimuth. This additional table could not be conveniently included in the accompanying reproduction.

43. Use of Azimuth Tables.—The arguments, or data, to be used for entering the Azimuth Tables are the apparent time, the latitude, and the declination. To find the apparent

TRUE BEARING OR AZIMUTH—Latitude 45°

DECLINATION—SAME NAME AS—LATITUDE

Dec.	12°	13°	14°	15°	16°	17°	18°	19°	20°	21°	22°	23°	Dec.
Apparent Time A. M.	April			May								June	Apparent Time P. M.
	21	24	27	1	4	7	11	15	20	25	31	10	
	August							July					
	21	18	15	12	8	5	1	28	23	18	12	2	
	October			November							December		
	25	27	30	3	6	9	13	17	21	26	2	11	
	February						January						
	17	14	11	8	5	1	29	25	20	15	9	1	
h. m.	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	h. m.
IV 30	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	58 58	58 18	30
40	. . .	. . .	. . .	. . .	. . .	. . .	. . .	62 41	62 01	61 21	60 41	60 02	20
50	. . .	. . .	. . .	. . .	. . .	65 47	65 07	64 27	63 46	63 05	62 25	61 44	10
V 00	. . .	. . .	. . .	68 55	68 14	67 33	66 51	66 11	65 29	64 48	64 07	63 26	VII 00
10	. . .	72 03	71 21	70 40	70 59	69 17	68 35	67 54	67 12	66 30	65 48	65 06	50
20	74 30	73 48	73 06	72 25	71 42	71 00	70 18	69 36	68 54	68 11	67 28	66 46	40
30	76 15	75 33	74 50	74 08	73 26	72 43	72 00	71 17	70 34	69 51	69 08	68 24	30
40	77 59	77 17	76 34	75 51	75 08	74 25	73 42	72 58	72 15	71 31	70 47	70 02	20
50	79 43	79 00	78 17	77 34	76 50	76 07	75 23	74 39	73 54	73 10	72 25	71 40	10
VI 00	81 27	80 44	80 00	79 16	78 32	77 48	77 04	76 19	75 34	74 49	74 03	73 18	VI 00
10	83 11	82 27	81 43	80 59	80 14	79 29	78 44	77 59	77 14	76 28	75 41	74 55	50
20	84 55	84 11	83 26	82 41	81 56	81 11	80 25	79 39	78 53	78 06	77 19	76 32	40
30	86 39	85 54	85 09	84 24	83 39	82 53	82 06	81 20	80 33	79 45	78 58	78 10	30
40	88 24	87 39	86 53	86 08	85 21	84 35	83 48	83 01	82 13	81 25	80 36	79 48	20
50	90 10	89 24	88 38	87 52	87 05	86 18	85 30	84 43	83 54	83 05	82 16	81 26	10
VII 00	91 57	91 10	90 24	89 37	88 50	88 02	87 14	86 25	85 36	84 46	83 56	83 05	V 00
10	93 44	92 58	92 11	91 23	90 36	89 47	88 58	88 08	87 18	86 28	85 37	84 45	50
20	95 34	94 47	93 59	93 11	92 23	91 34	90 44	89 54	89 03	88 12	87 20	86 27	40
30	97 24	96 38	95 50	95 01	94 12	93 22	92 32	91 41	90 49	89 57	89 04	88 10	30
40	99 19	98 31	97 42	96 53	96 03	95 13	94 22	93 30	92 37	91 44	90 50	89 55	20
50	101 14	100 26	99 37	98 47	97 57	97 05	96 13	95 21	94 27	93 33	92 38	91 42	10
VIII 00	103 12	102 24	101 34	100 44	99 53	99 01	98 08	97 15	96 20	95 25	94 29	93 32	IV 00
10	105 14	104 24	103 34	102 44	101 52	100 59	100 06	99 11	98 16	97 20	96 23	95 24	50
20	107 19	106 29	105 38	104 47	103 54	103 01	102 07	101 12	100 15	99 18	98 20	97 20	40
30	109 27	108 37	107 46	106 54	106 01	105 07	104 12	103 16	102 18	101 20	100 20	99 20	30
40	111 40	110 49	109 58	109 05	108 12	107 17	106 21	105 24	104 26	103 27	102 26	101 24	20
50	113 57	113 06	112 14	111 21	110 27	109 32	108 35	107 38	106 38	105 38	104 36	103 33	10
IX 00	116 19	115 28	114 36	113 43	112 48	111 52	110 55	109 56	108 56	107 55	106 52	105 47	III 00
10	118 47	117 55	117 03	116 10	115 15	114 19	113 21	112 21	111 21	110 18	109 14	108 39	50
20	121 20	120 29	119 37	118 43	117 48	116 51	115 53	114 53	113 52	112 48	111 43	110 36	40
30	124 00	123 10	122 17	121 24	120 29	119 32	118 33	117 33	116 33	115 26	114 20	113 12	30
40	126 47	125 57	125 05	124 12	123 17	122 20	121 21	120 21	119 18	118 13	117 06	115 57	20
50	129 42	128 52	128 01	127 08	126 14	125 17	124 18	123 18	122 15	121 10	120 02	118 52	10
X 00	132 45	131 56	131 06	130 14	129 19	128 24	127 25	126 25	125 23	124 17	123 09	121 59	II 00
10	135 56	135 08	134 19	133 28	132 36	131 40	130 43	129 44	128 42	127 37	126 29	125 19	50
20	139 15	138 30	137 42	136 53	136 02	135 09	134 13	133 14	132 13	131 10	130 03	128 53	40
30	142 44	142 01	141 16	140 29	139 39	138 48	137 54	136 57	135 58	134 56	133 51	132 42	30
40	146 22	145 41	144 59	144 15	143 28	142 39	141 48	140 55	139 58	138 58	137 55	136 48	20
50	150 09	149 32	148 53	148 12	147 29	146 43	145 56	145 05	144 12	143 16	142 17	141 13	10
XI 00	154 05	153 32	152 57	152 20	151 41	151 00	150 16	149 31	148 42	147 50	146 55	145 56	I 00
10	158 10	157 41	157 10	156 38	156 04	155 28	154 50	154 09	153 26	152 41	151 52	150 59	50
20	162 22	161 58	161 32	161 06	160 37	160 07	159 35	159 02	158 25	157 47	157 05	156 20	40
30	166 40	166 22	166 02	165 41	165 19	164 56	164 31	164 05	163 36	163 06	162 33	161 58	30
40	171 04	170 51	170 38	170 24	170 09	169 53	169 36	169 18	168 58	168 37	168 14	167 50	20
XI 50	175 31	175 25	175 18	175 11	175 03	174 55	174 46	174 37	174 27	174 16	174 05	173 52	XII 10

time (equal to hour angle of sun), note the reading of the chronometer at the instant of taking the compass bearing, and apply to this reading (properly corrected for rate) the longitude converted into time. The result will be the local mean time; and by applying to this the equation of time, according to its sign, the required local apparent time will be obtained. With the apparent time (expressed A. M. or P. M.), the latitude, and the declination, enter the proper table and take out the corresponding true azimuth, which is reckoned from north in north latitudes, from south in south latitudes, and toward east or west, according to whether the observation is made in the forenoon or in the afternoon.

EXAMPLE 1.—On May 19, 1899, in latitude 45° N and longitude 50° W, the sun's bearing, or azimuth, by compass, observed in the afternoon, was N 82° 30′ W. At the instant of taking the bearing, the Greenwich mean time by chronometer was $7^h\ 47^m$. The ship was headed E N E. The variation of locality according to chart is 30° W. Find the true azimuth and the deviation for heading.

SOLUTION.—Find first the local apparent time, as follows:

G. M. T. by Chron.	=	$7^h\ 47^m$ P. M.
Long. 50° W in time	=	$-\ 3^h\ 20^m$
L. M. T. at ship	=	$4^h\ 27^m$ P. M.
Eq. of T.	=	$+\ 3^m\ 42^s$
L. App. T., May 19	=	$4^h\ 30^m\ 42^s$ P. M.
Sun's Decl., May 19, 1899	=	N 19° 47′

In this case, the latitude and the declination have the same name, and therefore the second section of the Azimuth Tables is entered (see specimen page) with latitude 45° at the top, the nearest degree of declination, 20°, in its proper column, and the apparent time, $4^h\ 30^m$, in the side column marked P. M. Below the former and opposite the latter will be found the true azimuth, 90° 49′, which is named N 90° 49′ W since the latitude is north and the time P. M. Now compare the true azimuth with that observed by compass, using a diagram, or sketch, and find the deviation as before.

True azimuth	=	N 90° 49′ W. Ans.
Comp. azimuth	=	N 82° 30′ W
Total error	=	8° 19′ W
Variation	=	30° 0′ W
Dev. for E N E	=	21° 41′ E. Ans.

In Fig. 20, since the true azimuth $O\,S'$ falls to the left of the compass azimuth $O\,B$, the total error of the compass is westerly; and since the compass north falls to the right of the magnetic north, the resulting deviation is easterly.

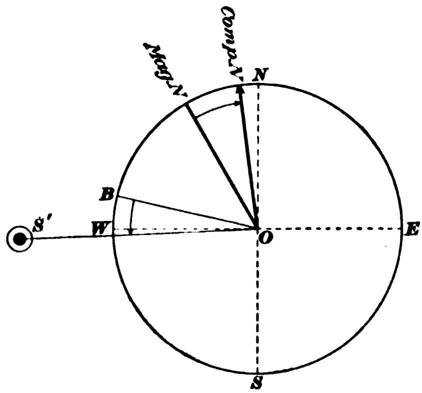


FIG. 20

EXAMPLE 2.—On November 6, 1899, about 10:30 A. M., in latitude 47° N and longitude 130° W, the sun's azimuth by compass was observed. At the instant of observation, the Greenwich mean time by chronometer was 7^h 11^m P. M., or 19^h 11^m A. M. Find the true azimuth.

SOLUTION.—

G. M. T. by Chron. =	$19^h\ 11^m$ A. M.
Long. 130° W in time =	$-\ 8^h\ 40^m$
L. M. T. at ship =	$10^h\ 31^m$ A. M.
Eq. of T. =	$+\ 16^m\ 16^s$
L. App. T. at ship =	$10^h\ 47^m\ 16^s$ A. M.
Sun's Decl., Nov. 6, 1899 =	S 16° 0′ 46″

In this case, the latitude and the declination have different names. Therefore, enter the third section of the Azimuth Tables and find there, for latitude 47°, declination 16°, and 10^h 50^m A. M. apparent time, the true azimuth, N 161° 23′ E. Ans.

EXAMPLE 3.—On July 7, 1899, about 4 o'clock in the afternoon, when the chronometer indicated 10^h 24^m 34^s, a bearing of the sun was taken. Latitude in = 27° N. Longitude in = 92° 30′ W. Find the true azimuth.

SOLUTION.—

G. M. T. by Chron. =	$10^h\ 24^m\ 34^s$
Long. 92.5° W in time =	$-\ 6^h\ 10^m\ 0^s$
L. M. T. at ship =	$4^h\ 14^m\ 34^s$ P. M.
Eq. of T. =	$-\ 4^m\ 38^s$
L. App. T. at ship =	$4^h\ 9^m\ 56^s$ P. M.
Sun's Decl., July 7, 1899 =	N 22° 35′.

In this case, the value of the declination is nearly $22\frac{1}{2}°$. Therefore, in picking out the azimuth from the tables, take the mean of the

azimuths given for declinations of 22° and 23°, respectively. Thus, for latitude 27°, apparent time 4^h 10^m P. M., and 22° of declination, an azimuth of 80° 23′ is obtained; and with the same latitude, apparent time, and 23° of declination, the corresponding azimuth is 79° 14′. Hence, the true azimuth is

$$\frac{80^\circ\ 23' + 79^\circ\ 14'}{2} = \frac{159^\circ\ 37'}{2} = \text{N } 79^\circ\ 48' \text{ W. Ans.}$$

EXAMPLES FOR PRACTICE

1. On February 7, 1899, at 5^h 48^m A. M., local apparent time, the sun's bearing by compass at rising was east. Heading of ship, N N W. Latitude in = 10° 20′ S. Longitude in = 1° 30′ W. Find the amplitude, the total error of the compass, and the deviation for heading, the variation according to chart being 22° 20′ W.

Ans. { Amp. = E 15° 36.5′ S
Total error = 15° 36.5′ E
Dev. for N N W = 37° 56.5′ E

2. On November 25, 1899, at 8^h 11^m 12^s P. M., local apparent time, when steering W by S, the sun's bearing by compass, at setting, was W $\frac{1}{4}$ N. Latitude in = 55° S. Longitude in = 122° 45′ E. Required, the total error of the compass and the deviation for heading, the variation by chart being 10° 1′ W.

Ans. { Total error = 41° 1′ W
Dev. for W by S = 31° W

3. In the morning of February 3, 1899, the observed altitude of the sun's lower limb was 16° 2′ 15″. Compass bearing at time of sight was S E by E $\frac{1}{4}$ E, the ship heading E by N. The chronometer, which was 2^m 15^s fast on Greenwich mean time indicated exactly at that instant, 9^h 30^m 45^s. At the time of observation, the position, by dead reckoning, was 47° 15′ N and 179° W. Height of eye = 23 feet. Index error = + 3′ 15″. Assuming the variation to be 24° E, what was (*a*) the sun's true azimuth? (*b*) the deviation of compass for this heading?

Ans. { (*a*) True azimuth = S 41° 38′ E
(*b*) Dev. for E by N = 6° 34′ W

4. On March 20, 1899, in latitude 56° 20′ S and longitude 63° 42′ W, at 4^h 4^m P. M., local mean time, when heading east, the observed altitude of the sun's upper limb was 16° 54′ 30″. Index error = + 1′ 1″. Height of eye = 27 feet. At the instant of measuring the altitude, the sun's bearing by compass was W $\frac{1}{4}$ S. Find the total error and the deviation for heading, the variation by chart being 24° 17′ E.

Ans. { Total error = 29° 17′ E
Dev. for east = 5° E

5. On September 1, 1899, in the forenoon, the observed altitude of the sun's upper limb was 34° 28′ 10″. Index error = − 2′ 25″. Height

of eye = 23 feet. Sun's bearing, by compass, at instant of observation = S E $\frac{1}{2}$ E. Latitude in = 44° 18′ N. Longitude in = 10° 15′ W. Course steered, W S W. Greenwich mean time at observation, August 31, $21^h\ 22^m\ 37^s$. Find the total error of the compass and the deviation, assuming the variation to be 12° W.

Ans. { Total error = 14° 48′ W
Dev. for W S W = 2° 48′ W

6. On July 2, 1899, at about $2^h\ 45^m$ P. M., the latitude and the longitude of a vessel were respectively 45° N and 51° 10′ W. The navigating officer deemed it advisable to test the accuracy of the deviation table for the four intercardinal points, and accordingly the compass bearing of the sun was taken when the ship was heading on these points successively and was found to be as follows:

Ship's Head	Mean Time Chronometer	Sun's Compass Bearing
N E	$6^h\ 18^m\ 34^s$	N 68° 38′ W
S E	$6^h\ 28^m\ 7^s$	N 87° 32′ W
S W	$6^h\ 38^m\ 25^s$	N 81° 17′ W
N W	$6^h\ 48^m\ 9^s$	N 62° 51′ W

The mean value of variation as taken from the chart is 30.2° W. Find by means of the Azimuth Table (see specimen page) the correct deviation of compass for these quadrantal points.

Ans. { Dev. for N E = 9° 49′ W
Dev. for S E = 11° 57′ E
Dev. for S W = 7° 56′ E
Dev. for N W = 8° 21′ W

7. On November 13, 1899, in the morning, in latitude 45° S and longitude 128° 30′ W, the sun's compass bearing, as found with an azimuth instrument, was N 61° 30′ E. At the instant of observation, the Greenwich mean time by chronometer was November 13, $5^h\ 18^m\ 44^s$ P. M. The ship was heading N N E. The variation of the locality, by chart, was found to be 17.5° E. Find by computation and also by the Azimuth Table (see specimen page): (*a*) the sun's true azimuth; (*b*) the deviation corresponding to this direction of the ship's head.

Ans. { (*a*) { True azimuth, by computation = S 110° 56′ E
True azimuth, by table method = S 110° 55′ E
(*b*) { Dev. for N N E, by computation = 9° 56′ W
Dev. for N N E, by table method = 9° 55′ W

AZIMUTH INSTRUMENTS

44. The best way of observing the compass bearing in amplitude and azimuth observations is to use what is known as an **azimuth instrument.** Different types of such instruments are now in use on shipboard, but the principles on which they are constructed are about the same. These

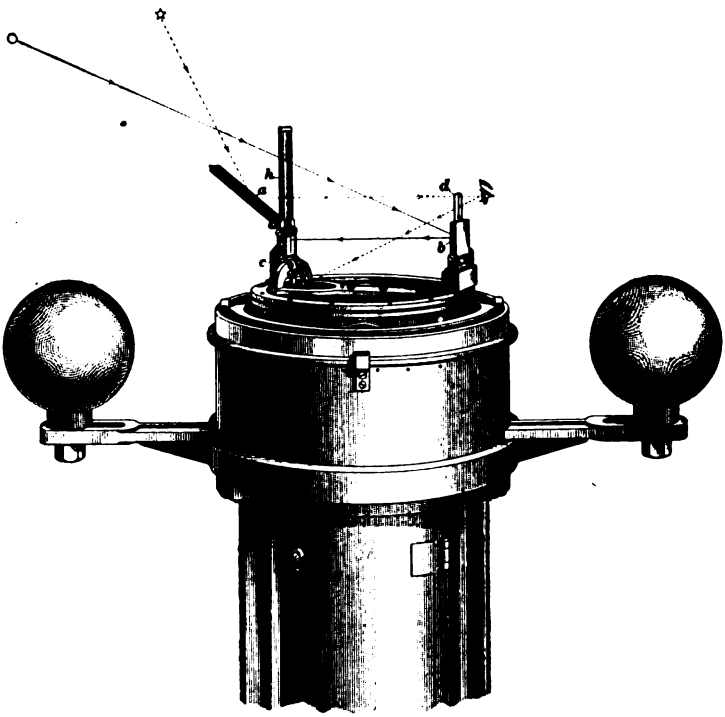


FIG. 21

instruments are very useful, because they afford a quick and accurate estimate of the bearing, and a convenient means of checking, at any time, the accuracy of deviation determined by the process of "swinging in port." For this reason, azimuth instruments should be included in the navigating equipment of every iron and steel vessel.

45. In Fig. 21 is shown an azimuth instrument attached to the compass and ready for use. The principal features of this instrument, which is known as the **Ritchie bar azimuth instrument,** are that it can be used for both star and sun observations and for taking the bearing of terrestrial objects. This instrument is provided with a black-glass reflector *a*, a mirror *b*, and a prism *c*, and is swung from a center post that enters a socket, or indentation, drilled in the center of the compass glass. When observing the bearing of the sun, the mirror *b* is inclined so that a ray of the sun (represented by a solid line) is reflected from *b* to the prism *c*. This ray enters the case holding the prism through a vertical slit shown in the figure, whence it is diverted downwards, appearing as a bright bar of light on the graduated card of the compass.

When observing a star, its light is reflected from *a* (see dotted line), in line with the vertical thread *h* on the sight vane, to the observer's eye, whence the bearing of the star is read through the slit *d* at the intersection of the horizontal hair line with the graduation on the card below. When taking bearings of terrestrial objects, the observer brings the object in line with *d* and *h* and reads off the bearing as before, being guided by the horizontal hair line.

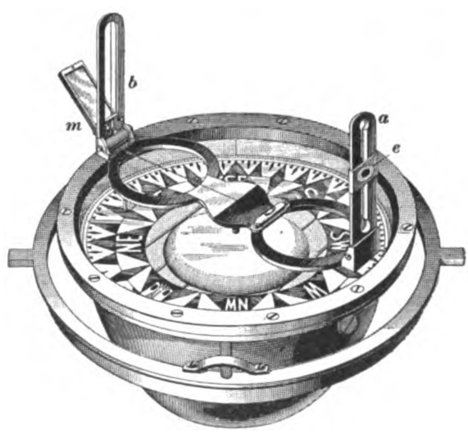


Fig. 22

46. Another type, called the **Bliss azimuth instrument,** is shown in Fig. 22. Like the instrument just described, it is fitted with two sight vanes *a* and *b* that are exactly opposite each other and in line with the center of the card when attached to the glass cover of the compass bowl.

Each sight vane has a vertical slit, the one in *a*, which is for the eye, being narrower than the one in *b*. The slit in *b* is fitted with a fine sight wire running vertically and exactly in the center of the vane. The instrument also has a horizontal wire running from the center to the vane *b*; this wire is used in reading the bearing. Both vanes are hinged and can be turned down when the instrument is not in use. The attachment *m* is a mirror, or reflector, and is used for azimuth observations. When making an observation for amplitude, this reflector is turned down. In taking a bearing, the observer places his eye to the eyepiece *e*, and adjusts the vanes so that the wire in *b* coincides exactly with the apparent center of the sun's disk. The bearing is then read by noting the point, or degree, on the compass card directly underneath the horizontal wire.

47. Pelorus, or Bearing Plate.—The **pelorus** is an instrument extensively used for measuring azimuth and for finding the deviation of the compass. This instrument, Fig. 23, consists of a metal compass dial that is engraved in points and quarter points. Surrounding the dial is a ring graduated in single degrees. Attached to the same center and moving on the same pivot as the dial, is a metal bar *a a* that is fitted with sight vanes *c* and *d* and a reflector *r*. The bar and dial can be clamped in any position desired. The whole is contained in a square wooden box and is suspended by means of gimbals, being kept in a horizontal position by a weight underneath. Screws fitted to one of the supporting arms *b* adjust the lubber line of the instrument to the ship's head. Before using the pelorus, the case holding it should be placed so that the lubber lines of the instrument are parallel with the fore-and-aft line of the ship. On the bridge, a suitable place fitted with four chocks should be provided for that purpose, in order that the case may be dropped into its place at any moment. The final adjustment of the instrument to the ship's fore-and-aft line is then made by the screws already referred to. The instrument may also be used without the box, in which case it is mounted on a

stand secured to the bridge or other suitable place, the stand being provided with sockets for the gimbals. As a rule, the height of this stand may be adjusted to suit the observer.

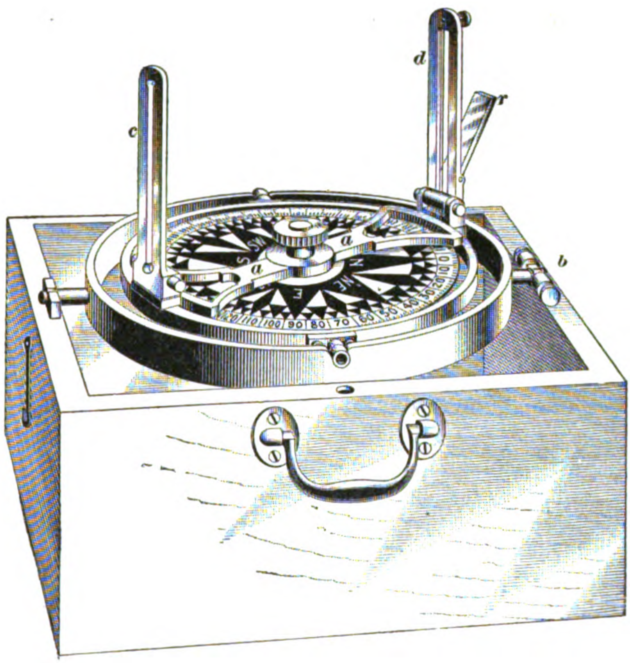


FIG. 23

48. Use of Pelorus in Heading Ship in Any Magnetic Direction.—If it is desired to head the ship in any required magnetic direction, this may be done conveniently by using the pelorus as follows:

On the date of observation select, beforehand, a suitable hour of local apparent time, and also estimate in advance the position of the ship for the hour in which the observation is to be made. With the latitude of the position thus found and the declination, enter the Azimuth Tables and find the true azimuth, or true bearing, of the sun for the selected hour of apparent time. Apply to this true azimuth the variation of the locality; the result will be the magnetic

bearing of the sun for the time selected. Shortly before the time selected, and when the ship has reached the position previously estimated, turn the dial of the pelorus so that the required magnetic heading is on the lubber line of the instrument; then turn the sight vanes of the instrument to correspond with the magnetic bearing of the sun previously found, and clamp both the dial and the sight vanes. Turn the ship by means of the rudder until the sight vanes are directed toward the sun, and keep them in this position until the exact instant of the local apparent time selected. At that moment the ship's head will correspond with the correct magnetic direction required; any difference shown by the compass at that time will be the deviation for that heading.

EXAMPLE.—Let it be required, on August 12, 1899, to head the ship correct magnetic north at, for instance, 3^h 10^m P. M, local apparent time. At the hour selected, the ship is estimated to be in latitude 45° N and longitude 60° W, the variation of that locality being about 24° W.

SOLUTION.—First find, from the Azimuth Tables, the true azimuth corresponding to the selected apparent time, the latitude estimated, and the declination for the date. The declination on August 12 is N 15° (nearly), latitude 45°, apparent time 3^h 10^m P. M.; hence, the azimuth as given in the table (see specimen page) is N 111° 21′ W. The variation applied to this gives the correct magnetic bearing of the sun at 3^h 10^m P. M. Thus,

$$\begin{aligned} \text{True azimuth} &= \text{N } 111^\circ\ 21'\ \text{W} \\ \text{Variation} &= \underline{\quad\ \ 24^\circ\ \ 0'\ \text{W}} \\ \text{Magnetic bearing} &= \text{N }\ 87^\circ\ 21'\ \text{W} \end{aligned}$$

Now, to make the observation at the correct local apparent time selected, the chronometer (corrected for rate) may be conveniently used, working back the apparent time to chronometer time by applying the equation of time as usual and the correction for longitude, as follows:

$$\begin{aligned} \text{Selected L. App. T.} &= \ \ 3^h\ 10^m \text{ P. M.} \\ \text{Eq. of T.} &= \underline{+\qquad 5^m} \\ \text{L. M. T.} &= \ \ 3^h\ 15^m \text{ P. M.} \\ \text{Long. } 60^\circ \text{ W in time} &= \underline{+\ 4^h\ \ 0^m} \\ \text{G. M. T.} &= \ \ 7^h\ 15^m \end{aligned}$$

The observation, therefore, is to be made when the chronometer shows 7^h 15^m. The pelorus is then placed in position, with the north point of its dial set to the ship's head and the sight vanes to N 87° W,

and both the dial and the vanes are clamped. A minute or two before the chronometer indicates $7^h\ 15^m$, turn the ship so that the vanes point directly toward the center of the sun, and keep them in this direction by means of the rudder until the chronometer shows $7^h\ 15^m$. At that instant, the ship is heading correct magnetic north. Suppose that the standard compass at that time shows N ½ E; the deviation will then be ½ point or 5.5° W. because the compass north falls to the left of the magnetic north.

49. Use of Pelorus in Finding Magnetic Course of Ship.—The pelorus may also be used for finding the deviation by clamping the sight bar at an angle that equals

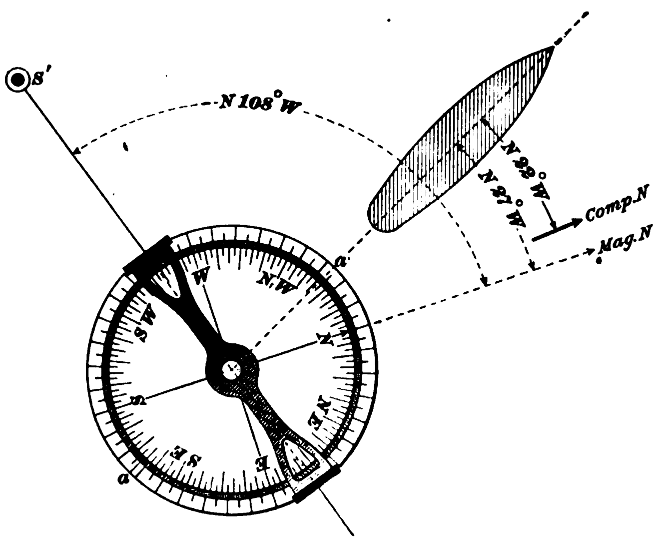


FIG. 24

the magnetic azimuth of the sun and then turning the vanes in range with the sun at the selected instant of apparent time. The lubber line of the pelorus will then indicate on the dial the magnetic course on which the ship is heading; by noting at the same time the heading of the ship by compass, the difference between the two will be the required deviation.

Assume that at a certain apparent time, say at $3^h\ 40^m$ P. M., the magnetic azimuth, or bearing, of the sun is N 108° W.

The bar of the pelorus is clamped to the dial at that angle, as shown in Fig. 24, and at exactly 3^h 40^m P. M. it is pointed toward the sun S'. The lubber line $a\,a$ of the pelorus, coinciding with the ship's fore-and-aft line, will now indicate the magnetic course on which the ship is heading. In this case, it will be seen that the ship is heading N 27° W (magnetic). Suppose that the heading of the ship by the compass at the same time is N 22° W. The deviation for heading of the vessel will then be $27° - 22° = 5°$ W, because compass north falls to the left of the magnetic north, as shown in the illustration.

50. In this manner, the magnetic course, or heading of the ship, may be found at any required time during a clear day, and the deviation ascertained. In practice, it is customary to select not only one instant of time, as in the preceding illustration, but to choose several instants of local apparent time, at intervals of, say, 10 minutes, and to find the deviation for each or every other point, as desired.

51. To Find True Course of Ship by Pelorus.—If it is required at any time to find the true course that the ship is heading, the sight vanes of the pelorus are set and clamped at an angle equal to the true azimuth, corresponding to time, declination, and latitude at observation. At the proper time, the sight vanes are swung in the direction of the sun; the lubber lines of the pelorus will then give the true course on which the ship is heading.

TO FIND THE DEVIATION BY POLARIS

52. Explanation and Direction.—By virtue of the proximity of Polaris to the north celestial pole (true north), this star is splendidly adapted for the determination of the compass error. In Table I is given the azimuth of Polaris for every hour of the 24, from latitude 10° to 60° N. All that should be known in order to use this table is the sidereal time at ship, and the latitude and longitude in, by dead reckoning. The following rule may therefore be formulated:

Rule.—*Take an accurate bearing of the star and note the time, either mean or apparent, at the ship. Find the sidereal time corresponding to this time. With the sidereal time thus found and the latitude, enter Table I and take out the corresponding azimuth. Then use the figure and find the error and deviation in the usual manner.*

TABLE I

AZIMUTH OF POLARIS

Sidereal Time at Ship Hours	Azimuth	Latitude N 10°	20°	30°	40°	45°	50°	60°	Azimuth	Sidereal Time at Ship Hours
0	E	0.4°	0.5°	0.5°	0.6°	0.6°	0.7°	0.9°	W	12
1	E	0.1°	0.1°	0.1°	0.1°	0.2°	0.2°	0.2°	W	13
2	W	0.2°	0.2°	0.2°	0.3°	0.3°	0.3°	0.4°	E	14
3	W	0.5°	0.5°	0.6°	0.7°	0.7°	0.8°	1.0°	E	15
4	W	0.8°	0.8°	0.9°	1.0°	1.1°	1.2°	1.6°	E	16
5	W	1.0°	1.1°	1.2°	1.3°	1.4°	1.6°	2.1°	E	17
6	W	1.2°	1.2°	1.3°	1.5°	1.6°	1.9°	2.3°	E	18
7	W	1.2°	1.3°	1.4°	1.6°	1.7°	1.9°	2.5°	E	19
8	W	1.2°	1.3°	1.4°	1.6°	1.7°	1.9°	2.4°	E	20
9	W	1.1°	1.2°	1.3°	1.5°	1.6°	1.7°	2.2°	E	21
10	W	1.0°	1.0°	1.1°	1.2°	1.3°	1.5°	1.9°	E	22
11	W	0.7°	0.8°	0.8°	0.9°	1.0°	1.1°	1.4°	E	23

Example.—On May 10, 1899, in latitude 20° 30′ N and longitude 37° W, at 4^h 18^m A. M., local mean time, when heading W N W the bearing by the standard compass of the pole star was found to be N by E. Find the deviation for heading of ship, the variation by chart being 15° 6′ W.

Solution.— L. M. T., May 10 = 4^h 18^m A. M.
L. M. T., May 9 = 16^h 18^m
Long. (W) in time = + 2^h 28^m

G. M. T., May 9 = 18^h 46^m
Sid. time G. M. N. = 3^h 8^m 19.7^s
Table III, Corr. for 18^h 46^m = 3^m 5^s

R. A. M. S. = 3^h 11^m 25^s
L. M. T. = 16^h 18^m 0^s

Sid. time at ship = 19^h 29^m 25^s

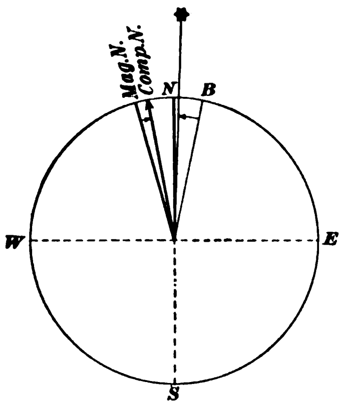


FIG. 25

Now, entering Table I with latitude 20° in the top row and the sidereal time 19^h in the side column to the right below the former and opposite the latter, is found the required azimuth, 1.3° E, the name of the azimuth being taken from the same side as the sidereal time. Hence,

True azimuth =	N 1° 18′ E	
Comp. bearing =	N 11° 15′ E (= N by E)	
Total error =	9° 57′ W	Fig. 25
Variation =	15° 6′ W	Fig. 25
Dev. for W N W =	5° 9′ E. Ans.	

53. It is evident that by the aid of Table I the error of the compass may be detected at any time of the night, provided the weather is clear and the ship's latitude is within the limits of the table. Furthermore, since the apparent motion of Polaris is very slow, the change of its azimuth is, comparatively, still slower, especially at its eastern and western elongation. At these points, the azimuth may be considered, without any practical error, as constant for 30 or 40 minutes. For this reason, the pole star is admirably suitable for use in swinging the ship and for determining the deviation on all points of the compass.

54. Swinging the Ship at Sea.—The method of swinging a ship at sea, for determining the deviation of all points of the compass, is practically the same as when swinging it in a harbor, the only difference being that, at sea, the operation is performed by the ship's own motive power, whether steam or sail, and that the use of hawsers, tugs, etc. is entirely done away with. Moreover, since the distance of the object selected (sun, planet, or star) is

enormously great, it does not matter whether the diameter of the circle in which the ship is swung is 50 fathoms or a mile. The presentation of any particular rule or method of swinging a ship at sea is quite unnecessary, since this will depend entirely on circumstances as well as on the discretion of the officer in charge. The general requirements are that the weather be moderate, the sea comparatively smooth, and the altitude of the selected body as low as possible.

55. To Find the Deviation at Sea in Calm, Foggy Weather.—On an iron or steel ship, at sea, in calm, foggy weather and smooth water, it is sometimes practicable to find the deviation of the compass by launching a boat, placing a good liquid compass in it, and pulling some distance away (say half a mile, or as far away as the fog permits), and then by means of prearranged signals taking reciprocal bearings, while the ship is slowly swung around, either by steam or by being pulled, or towed, by a second boat launched for that purpose. The bearings of the ship taken by the compass in the boat, being uninfluenced by the magnetism of the ship, are, of course, *magnetic bearings*, while the bearings of the boat, taken on board, are *compass bearings*. The deviation is then found in the usual way by comparing the magnetic bearings (reversed) with the compass bearings.

This method may prove useful on voyages in regions of the sea where considerable fog and calm weather is encountered; as, for instance, on the passage between San Francisco and the Bering Sea, on the banks of Newfoundland, etc.

SUMNER'S METHOD

ESTABLISHMENT OF LINES OF POSITION

DETERMINATION OF LINES OF POSITION, OR SUMNER LINES, BY ASTRONOMICAL OBSERVATIONS

1. Principles Involved.—**Sumner's method** consists essentially in fixing a ship's position at sea by astronomical cross-bearings or by intersecting lines of position. It will be remembered that when determining a ship's position by cross-bearings of two known terrestrial objects *A* and *B*, Fig. 1, their respective bearings *A a* and *B b* are plotted, or laid down, on the chart. The ship must therefore be on both of these lines and, consequently, cannot be at any other point than at *s*, where the two lines intersect. Now, suppose that instead of knowing the bearings of the two objects, the ship's distance from *A* is known to be 5 miles, and her distance from *B* 4 miles. Then, in order to find the ship's

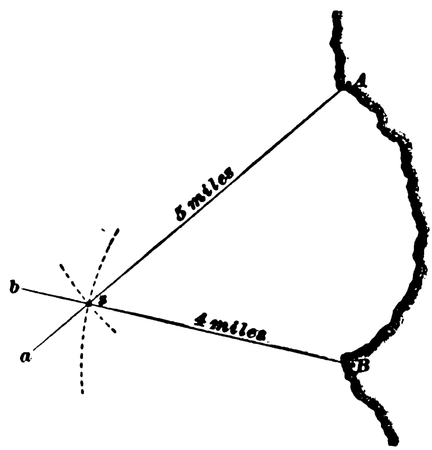


FIG. 1

§ 16

position, it would be necessary to describe an arc with A as a center and a radius equal to 5 miles, and another with B as a center and a radius of 4 miles. The point of intersection of these arcs is, of course, the position of the ship. The bearings of celestial bodies, such as the sun, the planets, and the stars, may be used in the same manner to establish points of intersection, as will be shown in the following pages.

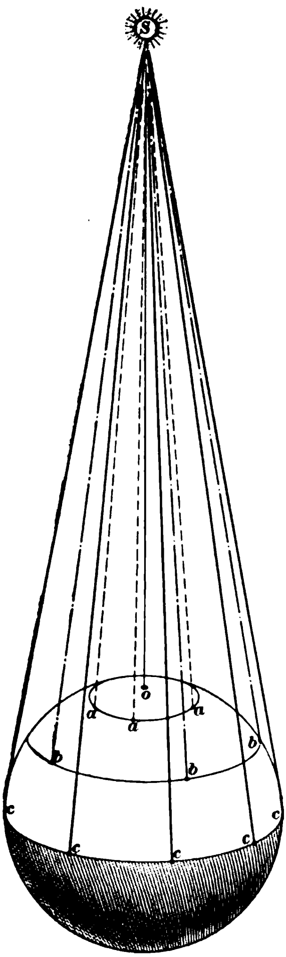


Fig. 2

2. Circles of Equal Altitude. At any given moment there is always one spot on the earth's surface that has the sun in its zenith. Let this spot be *o*, Fig. 2, and let S represent the sun. Then that hemisphere of the earth which has *o* as its pole is illuminated by the sun while the other hemisphere is dark, and the boundary between the two, the great circle *c c c*, is called the *circle of illumination*. Now, if small circles are drawn on the earth's surface parallel to the circle of illumination, it is evident that the altitude of the sun will be the *same* at each point of any such circle. In other words, observers stationed at points *a* along the first circle will get the same altitude of the sun, if measured simultaneously. The same result will be obtained by observers stationed at points *b* along the second circle, although the altitudes observed on that circle will be *less* than those observed on the first circle, because the sun is farther from their zenith. To observers at points *c*, the sun will be on the

horizon, or nearly so. These circles may, therefore, be called **circles of equal altitude.** From the figure, it is evident also that a circle of equal altitude, or the tangents of which it is composed, will always be *perpendicular* to the direction, or true bearing, of the sun.

3. Lines of Position, or Sumner Lines.—From the foregoing it may be concluded that whenever an altitude of the sun is measured, the observer must be somewhere on a circle of equal altitude. If, then, another altitude is measured when the sun has changed its bearing sufficiently, it is evident that the observer is on another circle of equal altitude. His actual position must therefore be on one of the two points in which these circles intersect; and since these points, as a general rule, are far apart, his position, by dead reckoning, will enable him to determine which point of intersection is the correct one. Thus, in Fig. 3, if the sun is directly above the point Z, the circle to the right being the first circle of equal altitude, and the circle to the left, when the sun has changed to Z_1, being the second circle of equal altitude, then the observer must be at either A or A_1; and since A is a great distance to the north of A_1, being separated by several degrees, the correct position is readily determined.

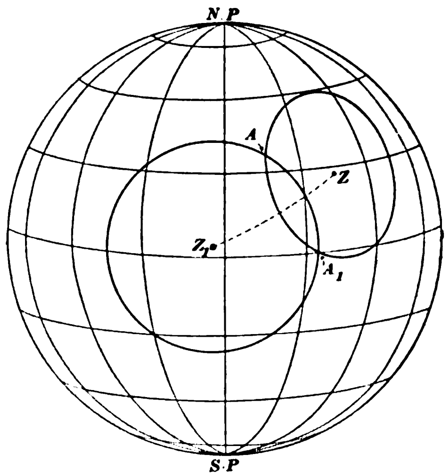


FIG. 3

If, now, these circles of equal altitude are transferred to a Mercator's chart, they will be represented by gigantic curves, any small portion of which may, for all practical purposes, be considered as a straight line; such straight

line is termed a **line of position**, or a **Sumner line.** Thus, in Fig. 4, the small portions *m n* and *t u* of the curves intersecting at *a* are Sumner lines, each of which is perpendicular to the true bearing of the sun S and S_1 at the instant of making the observation.

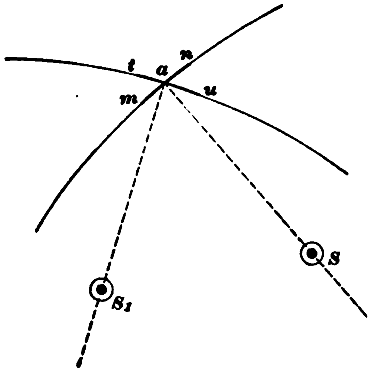


FIG. 4

4. Important Conclusions Derived From the Sumner Line.—From the fact that the direction of a Sumner line is always at right angles to the true bearing of the sun, some important conclusions may be deduced. In the first place, when the sun is on or near the prime vertical, or when its bearing is true east or west, the Sumner lines

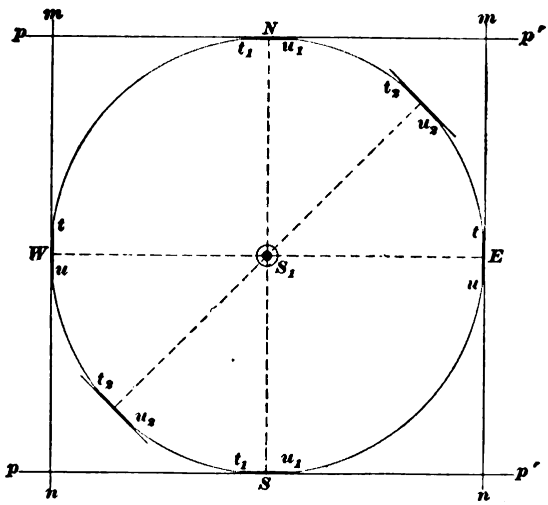


FIG. 5

resulting from observations taken at such instances will, accordingly, run north and south. Thus, in Fig. 5, if S_1 represents the sun and *m n* the direction of the meridians, the

Sumner lines *t u* obtained from observations made when the sun bears either *W* or *E* will run exactly north and south, as shown in the figure. At these points, therefore, or when the sun is on or near the prime vertical, it will make little difference whether the latitude of the observer is correct or not, for the longitude will remain nearly the same for a long distance in latitude. This explains why observations for longitude should be made when the selected body is on or near the prime vertical.

5. Secondly, when the sun is on the meridian or its bearing is true north or south, as at *N* and *S*, the Sumner

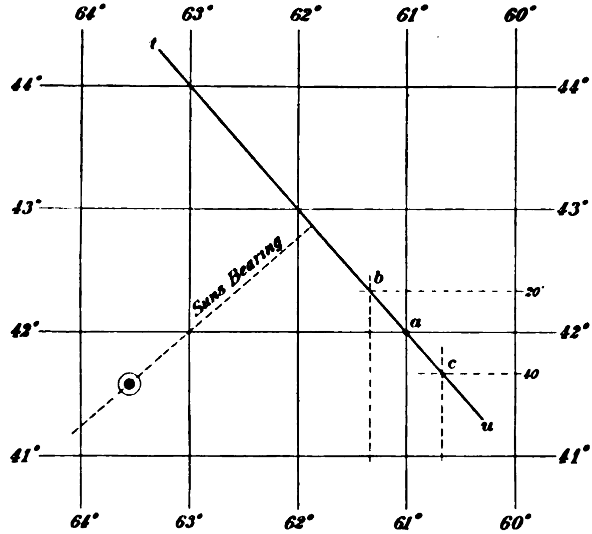


FIG. 6

lines $t_1 u_1$ resulting from observations made under such conditions will necessarily run east and west, or in the direction of the parallels of latitude $p p'$, as shown in Fig. 5. An error in declination resulting from an error in longitude will then have only a slight or no effect on the latitude. This explains very clearly why observations for latitude should be made when the observed body is on or near the meridian.

When the bearing of the sun is in the direction of any of the intercardinal points, for instance southwest or northeast,

the resulting Sumner lines *t*, *u*, will run in a northwest-and-southeast direction, and will intersect the meridian at an angle of 45°. For observations made at these positions, it is evident that an error in latitude will produce a correspondingly large error in longitude; and, conversely, an error in longitude will produce a corresponding error in the resulting latitude. This is more clearly illustrated in Fig. 6, which represents a Mercator's chart, on which the Sumner line *t u*, running in a northwest-and-southeast direction, is projected. The position of the observer should be somewhere on that line. Assume his latitude to be 42° N; his position must then be at the point *a* where the parallel of 42° intersects the Sumner line, and his longitude in this case will be 61° W. But, suppose that the latitude is in error, say, for instance, 20′ on either side; the position of the observer must then be either at *b* or at *c*. If the latitude (42°) is 20′ too large, he is at *c*; if it is 20′ too small, he is at *b*, and a glance at the figure will show at once that the resulting longitude is correspondingly affected. An error in longitude in this case will produce similar results in the corresponding latitude. From this fact it will be seen how important it is, in determining the longitude, to know the latitude exactly, in cases where the observed body is not on or near the prime vertical.

6. How to Obtain a Sumner Line.—A Sumner line can be obtained whenever a time sight of the sun or any other celestial body is observed, and the calculations are the same as those that have already been performed in examples for longitude and altitude azimuths. For instance, in the morning when measuring the sun's altitude for a time sight, the observer calculates the longitude, using the same data for calculating the true azimuth (or finds the azimuth directly from tables). The azimuth is, of course, the sun's true bearing at the moment that the altitude is measured. He then plots on the chart the longitude found and the latitude used in the computation, and through the position thus found, he draws a line perpendicular to the sun's true bearing or azimuth. *This line is his Sumner line;* he must be

somewhere on this line, provided his chronometer is not wrong and no errors have been made in the computations. His exact position on that line will depend on the exactness of the latitude used; but, whatever may be the error in the latitude, whether it is 10′ or 20′, the navigator will have the great satisfaction of knowing that he is *on that line*, and this knowledge may, under certain circumstances, prove very valuable.

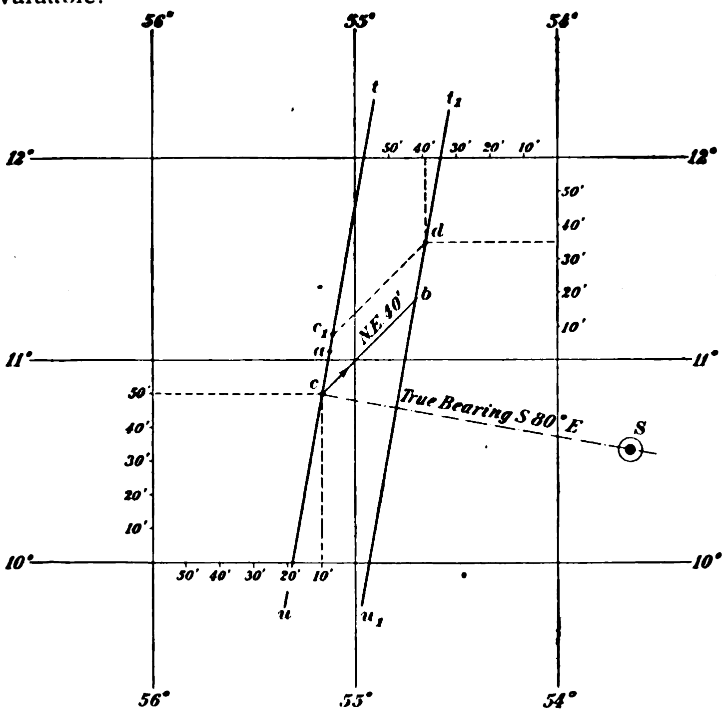


FIG. 7

7. Graphic Representation.—To exemplify the foregoing, assume that a time sight of the sun has been observed in the morning and that the longitude computed is 55° 10′ W; the latitude in, by dead reckoning, and which was used in calculating the longitude, is 10° 50′ N, the azimuth, or true bearing of the sun, being S 80° E. Then, through the point *c*, Fig. 7, in latitude 10° 50′ N and longitude

55° 10′ W, draw a line Sc in the direction of the sun's true bearing S 80° E, and through the same point c, perpendicular to Sc, draw the line tu. This line is the Sumner line corresponding to the time when the observation was made, and on this line is the position of the ship. The latitude in, by dead reckoning, is uncertain, however, but at noon a correct value of the latitude is obtained by a meridian altitude, and it is then found to be 11° 3′ N. The observer's exact position is therefore at the point a, on the line tu, provided the ship has been at anchor or otherwise has not changed her position since making the observation for longitude.

8. Plotting a Noon Position.—In the preceding article, it was assumed that the ship had been stationary. Suppose, however, that the ship has changed her position; that from the time of observation in the morning until noon she has sailed, or steamed, on a course, say, true N E 40 miles, and that the latitude by meridian altitude at noon was 11° 35′ N. Then, in order to find the position at noon, the method of procedure would be as follows: From the point c, the position calculated from the morning observation, or, in fact, from any point on tu, lay off the course and distance run in the interval, or N E 40 miles, and through the extremity b of this line draw a line $t_1 u_1$ parallel to the original Sumner line tu. The point d, where this second line $t_1 u_1$ intersects the latitude parallel of 11° 35′ N, is the true position of the ship at noon.

By the position thus found, the longitude in at noon is readily determined by inspection of the chart—in this case 54° 40′ W, nearly (see Fig. 7). If it is desired to know what the exact position of the ship was at the morning observation, simply draw, toward tu, a line from d parallel to the course sailed; the point c_1, where this line intersects the original Sumner line tu, was the exact position of the ship at that time. The latitude used in computing the hour angle was therefore nearly 18′ wrong, to the south.

Thus, it should be evident that by using a Sumner line in the manner shown there is no particular necessity of recalculating the longitude with the new value of latitude obtained at noon (corrected for run) and then, by dead reckoning, carrying it up to noon. Instead, the longitude in at noon may be quickly and accurately found by mere inspection.

9. Intersecting Sumner Lines.—Thus far only a *single* Sumner line has been considered, and it has been shown what valuable information may be deduced from it; obviously, then, a great deal more might be obtained from *two* Sumner lines that cross, or intersect, each other at an angle sufficiently great to insure a defined point of intersection. Since the ship must be on each and both of these lines, it is evident that her exact position must be at their point of intersection. If, therefore, one observation for time sight is made early in the morning and another some time later, when the bearing of the sun has changed at least two points, two Sumner lines are obtained whose point of intersection will be the position of the ship, provided the ship has not moved in the interval between the observations. But in case the ship has changed her position in the interval, which is more likely, the first Sumner line is carried forwards, *parallel to itself*, according to the course and distance run (as in Fig. 7), when its intersection with the second Sumner line will be the position of the ship at the time the second observation is made.

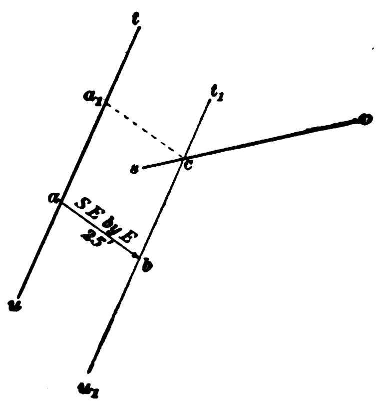


FIG. 8

To illustrate this, let the line tu, Fig. 8, be the Sumner line obtained by the first observation, and sv the Sumner line resulting from the second observation, and assume the

course and distance run in the interval to be S E by E 25 miles. Then, to find the ship's position at both observations, proceed as follows: From *any* point a on the first Sumner line tu lay off the course and distance run in the interval between observations, and at the extremity b of this line ab, draw $t_1 u_1$ parallel to the first Sumner line, so as to intersect the second Sumner line sv. The point c where $t_1 u_1$ crosses the second Sumner line will be the position of the ship at the time of the second observation, and a_1 her position at the first observation.

10. Angle of Intersection.—In order to obtain accurate results, it is evident that the angle between the two Sumner lines should be sufficiently large, so that a good intersection is established. The angles should not be less than 25° nor more than 155°; in other words, the bearing of the sun must change *at least two points* before the second observation is made.

11. Simultaneous Observations.—Simultaneous observations of two celestial objects are unquestionably the best for determining the position of a ship. Two Sumner lines are then obtained that require no allowance for a change of time or place, the ship's position being, of course, at their point of intersection. Such observations, though preferable, are not available in the daytime; but at night, and especially at twilight, the ship's position can be satisfactorily determined by simultaneous observations of two stars. In selecting the stars, care should be taken that their difference in bearing is between 60° and 120°, so as to develop a good point of intersection between the two resulting Sumner lines.

When simultaneous observations of different objects are made the hour angles are, of course, calculated with the same latitude; namely, the latitude in by dead reckoning. Consequently, both longitudes found by calculation from those observations should agree; if they do not, the latitude by dead reckoning is faulty.

12. Effect of an Error of the Chronometer on the Sumner Line.—It should be borne in mind that in whatever

way Sumner's method is utilized, the *correctness of the position of a Sumner line depends mainly on the accuracy of the chronometer.* If the chronometer is *faster* on Greenwich mean time than is supposed, the Sumner line will be to the *west* of its correct position, and if *slower*, it will be to the *east*, but its direction will not be altered. Thus, in Fig. 9, let $t\,u$ represent a Sumner line obtained by a chronometer indicating *correct* Greenwich mean time. Then, in case the chronometer had been too fast, the resulting Sumner line $t_1\,u_1$ would be to the west of its correct position $t\,u$, and if the chronometer was too slow the resulting Sumner line $t_2\,u_2$ would be to the east of $t\,u$ by an amount equal to the error of the chronometer, but the *direction* of the line would not be changed.

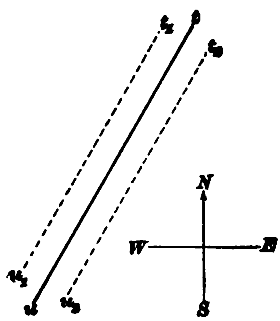


Fig. 9

This suggests another precaution. Suppose there is reason to suspect that the chronometer is wrong, say 1 minute, fast or slow, but it is not known which. Then, having obtained the Sumner lines $t\,u$ and $s\,v$, Fig. 10, it will be necessary to lay off at a distance of 15′ (= 1^m) on both sides and parallel to each Sumner line, the dotted lines, as shown, so as to make the distance between each pair of dotted lines equal to 30′. The ship's position may now be regarded to be, not at a positive point of intersection, but within the space $a\,b\,c\,d$ formed by the lines representing the error of the chronometer.

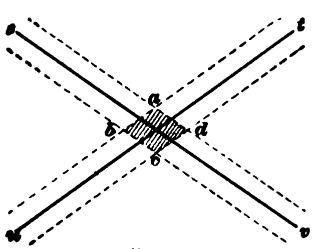


Fig. 10

13. Effect of an Error in the Altitude on the Sumner Line.—An error in the observed altitude, and consequently in the hour angle, affects the position of the Sumner line in exactly the same way as an error of the chronometer. This error in the altitude does not alter

the direction of the line, but moves it parallel to itself, either from or toward the observed body, by an amount equal to the error in altitude. This is shown in Fig. 11, where the correct altitude of the body S is represented by the angle $S o h$, $t u$ being the corresponding Sumner line. If the measured altitude is too large, as at a, the resulting Sumner line will evidently be moved nearer the observed body, and if the altitude is too small, as at b, it will be moved farther from the observed body, as shown, but its *direction* will not be changed. Having confidence in the

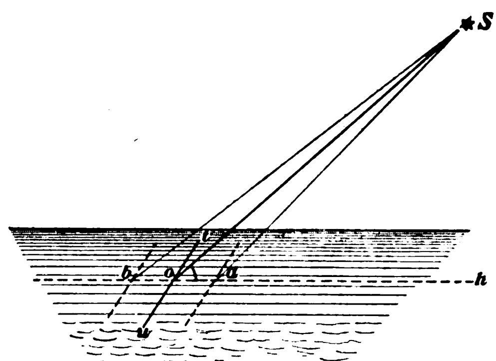


FIG. 11

chronometer and knowing how to properly estimate the error in altitude (if any), there is no reason why the Sumner line should not be correct and trustworthy.

14. Methods of Calculating Sumner Lines.—The method commonly used for finding the direction and position of a Sumner line is to assume two latitudes 10′, 20′, or 30′ apart, at equal distances from the latitude by account, and to calculate the longitude with each, thus obtaining two positions. These positions are then plotted on the chart and connected by a straight line, which will be the required Sumner line. For instance, if the latitude by account of a ship at A, Fig. 12, is 42°, two latitudes, say 20′ on either side of A, are assumed. The longitude for both assumed latitudes, 41° 40′ and 42° 20′, respectively, is then worked out, but the *same altitude* is used in both computations. From what is known of circles

of equal altitude, it is evident, then, that the two positions thus found must lie on the same line perpendicular to the true bearing of the sun (assuming that body to be observed), or on the same circle of equal altitude $x\,x'$, since the altitudes in both computations are identical. Hence, the straight line $t\,u$ connecting these positions is the required Sumner line. As stated before, this is the method more commonly used for establishing a line of position, or Sumner line. It is known as the *chord method*, and involves the calculation of two longitudes for each line, making a total of four longitude calculations to establish a point of intersection.

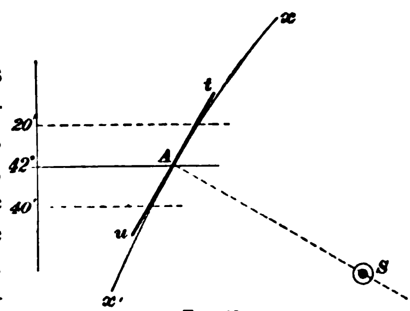


FIG. 12

15. Another and less laborious method of establishing two Sumner lines, is to note the true azimuth, or true bearing, of the observed body at the time of measuring the altitudes. Only two longitude calculations are then required, the directions of the lines being determined by the azimuth observed at each sight. Thus, in Fig. 12, if the latitude by account (42°) is used, A being the resulting position and $A\,S$ the true bearing, it is evident that a line drawn through A perpendicular to $A\,S$ will be the required Sumner line, and will consequently pass through the points t and u situated, as they are, on a curve of equal altitudes. It follows, therefore, that the latter method, which is known as the *tangent method*, is more convenient, and, being just as accurate, is considered by many preferable to the chord method, especially when the true azimuth is not calculated but is found directly by inspection of the Azimuth Tables. The illustrative example that follows is worked out by both methods and shows each process and the results attained by both. Careful attention should be given to both solutions, the diagrams on which lines are plotted, and the interposed comments.

EXAMPLE.—On April 26, 1899, at about 10 A. M., an altitude of the sun's upper limb was measured and found to be 59° 42′ 50″. The chronometer reading at the instant of observation was $10^h\ 32^m\ 30^s$, April 25. Latitude by account = 33° 30′ N. In the afternoon, after running true N N E 40 miles and when the chronometer showed $15^h\ 52^m\ 47^s$, April 25, a second observation of the sun's lower limb gave its altitude as 36° 39′ 50″. The error of the chronometer on the Greenwich mean time at both observations was $11^m\ 34^s$ fast. Height of eye = 28 feet. Index error of sextant = + 3′ 41″. Find, by calculation and plotting of Sumner lines, the true position of the ship at the second observation.

SOLUTION BY FIRST METHOD.—First find the Greenwich mean time at the A. M. observation. Pick out and correct the declination and equation of time, as usual. Reduce the altitude to true, and calculate two longitudes, using two assumed latitudes at equal distances on either side of the latitude by account, say 20′, as follows:

$$\begin{aligned}
\text{Chronometer} &= 10^h\ 32^m\ 30^s \\
\text{Error (fast)} &= -\quad 11^m\ 34^s \\
\text{G. D., or G. M. T., Apr. 25} &= 10^h\ 20^m\ 56^s, \text{ or } 10.3^h
\end{aligned}$$

☉Decl., Apr. 25	= N 13° 12′ 43.3″	Change in 1^h	= 48.8″
Corr. for 10.3^h	= + 8′ 22.6″		$\times\ 10.3^h$
Corr. Decl.	= N 13° 21′ 5.9″	Corr.	= 502.64″
	90° 0′ 0″	Or	= 8′ 22.6″
P. D.	= 76° 38′ 54″		
Eq. of T., Apr. 25	= $2^m\ 4.8^s$	Change in 1^h	= $.44^s$
Corr. for 10.3^h	= + 4.5^s		$\times\ 10.3^h$
Corr. Eq. of T.	= $2^m\ 9.3^s$ (−)	Corr.	= 4.532^s

$$\begin{aligned}
\text{Obs. Alt. } \bar{\odot} &= 59°\ 42'\ 50'' \\
\text{I. E.} &= +\quad 3'\ 41'' \\
&\ 59°\ 46'\ 31'' \\
\text{Dip} &= -\quad 5'\ 11'' \\
&\ 59°\ 41'\ 20'' \\
\text{S. D.} &= -\quad 15'\ 56'' \\
&\ 59°\ 25'\ 24'' \\
\text{Par. Ref} &= -\quad 0'\ 29'' \\
\text{T. Alt., or } a &= 59°\ 24'\ 55''
\end{aligned}$$

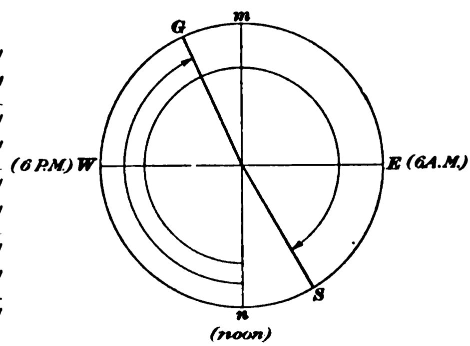


FIG. 13

The latitude by account being 33° 30′ N, if latitudes of 20′ on either side are used, work out longitudes with latitudes 33° 10′ and 33° 50′ N, respectively, and designate the results with the letters A and B. Thus,

$$
\begin{array}{rll}
a = & 59^\circ\,24'\,55'' & \\
p = & 76^\circ\,38'\,54'' & \text{cosec} = 0.01190 \\
l = & \underline{33^\circ\,10'\;\;0''} & \text{sec} = 0.07723 \\
& 2)\,169^\circ\,13'\,49'' & \\
S = & 84^\circ\,36'\,54'' & \text{cos} = 8.97242 \\
S - a = & 25^\circ\,11'\,59'' & \text{sin} = \underline{9.62918} \\
& & \quad 2)\,18.69073
\end{array}
$$

log sin $\frac{1}{2}$ H. A. = 9.34536

L. App. T., Apr. 26 = $10^h\,17^m\,38^s$ A. M.

Eq. of T. = $-\;\;2^m\;9^s$

L. M. T., Apr. 26 = $10^h\,15^m\,29^s$ A. M.

Fig. 13 { Or, Apr. 25 = $22^h\,15^m\,29^s$ P. M.

Fig. 13 { G. M. T., Apr. 25 = $10^h\,20^m\,56^s$ P. M.

Diff. = $11^h\,54^m\,33^s$

Long. A = $178^\circ\,38.3'$ E

$$
\begin{array}{rll}
a = & 59^\circ\,24'\,55'' & \\
p = & 76^\circ\,38'\,54'' & \text{cosec} = 0.01190 \\
l = & \underline{33^\circ\,50'\;\;0''} & \text{sec} = 0.08058 \\
& 2)\,169^\circ\,53'\,49'' & \\
S = & 84^\circ\,56'\,54'' & \text{cos} = 8.94475 \\
S - a = & 25^\circ\,31'\,59'' & \text{sin} = \underline{9.63451} \\
& & \quad 2)\,18.67174
\end{array}
$$

log sin $\frac{1}{2}$ H. A. = 9.33587

L. App. T., Apr. 26 = $10^h\,19^m\,53^s$ A. M.

Eq. of T. = $-\;\;2^m\;9^s$

L. M. T., Apr. 26 = $10^h\,17^m\,44^s$ A. M.

Fig. 13 { Or, Apr. 25 = $22^h\,17^m\,44^s$ P. M.

Fig. 13 { G. M. T., Apr. 25 = $10^h\,20^m\,56^s$ P. M.

Diff. = $11^h\,56^m\,48^s$

Long. B = $179^\circ\,12'$ E

Now calculate two longitudes from the P. M. sight, using the same assumed latitudes as in the A. M. sight, and denote the results C and D, respectively. Thus,

Chronometer = $15^h\,52^m\,47^s$

Error (fast) = $-\;\;11^m\,34^s$

G. D., or G. M. T., Apr. 25 = $15^h\,41^m\,13^s$, or 15.7^h

⊙ Decl., Apr. 26 =	N $13^\circ\,32'\;\;8.4''$	Change in 1^h =	$48.3''$
Corr. for 8.3^h =	$-\qquad 6'\,40.9''$		$\times\,8.3^h$
Corr. Decl. =	N $13^\circ\,25'\,27.5''$	Corr. =	$400.89''$
	$90^\circ\;\;0'\;\;\;0''$	Or =	$6'\,40.9''$
P. D. =	$76^\circ\,34'\,32.5''$		

Eq. of T., Apr. 26 =	$2^m\,15.2^s$	Change in 1^h =	$.42^s$
Corr. for 8.3^h =	$-\;\;3.5^s$		$\times\,8.3^h$
Corr. Eq. of T. =	$2^m\,11.7^s$ $(-)$	Corr. =	3.486^s

Obs. Alt. ☉	=	36° 39′ 50″
I. E.	=	+ 3′ 41″
		36° 43′ 31″
Dip	=	− 5′ 11″
		36° 38′ 20″
S. D.	=	+ 15′ 56″
		36° 54′ 16″
Par. Ref.	=	− 1′ 10″
T. Alt., or a	=	36° 53′ 6″

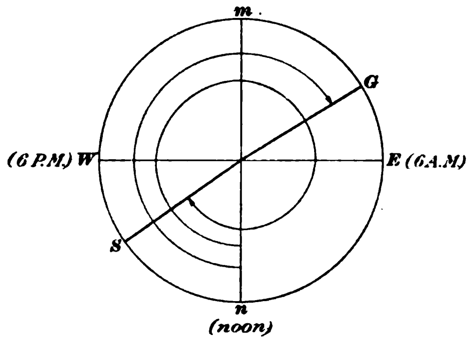


FIG. 14

a	=	36° 53′ 6″			
p	=	76° 34′ 33″	cosec	=	0.01203
l	=	33° 10′ 0″	sec	=	0.07723
	2)	146° 37′ 39″			
S	=	73° 18′ 49″	cos	=	9.45809
$S-a$	=	36° 25′ 43″	sin	=	9.77365
				2)	19.32100
			log sin ½ H. A.	=	9.66050
			L. App. T., Apr. 26	=	$3^h\ 37^m\ 52^s$ P. M.
			Eq. of T.	=	− $2^m\ 12^s$
			L. M. T., Apr. 26	=	$3^h\ 35^m\ 40^s$ P. M.
Fig. 14			Or, Apr. 25	=	$27^h\ 35^m\ 40^s$ P. M.
			G. M. T., Apr. 25	=	$15^h\ 41^m\ 13^s$ P. M.
			Diff.	=	$11^h\ 54^m\ 27^s$
			Long. C	=	178° 36.8′ E

a	=	36° 53′ 6″			
p	=	76° 34′ 33″	cosec	=	0.01203
l	=	33° 50′ 0″	sec	=	0.08058
	2)	147° 17′ 39″			
S	=	73° 38′ 49″	cos	=	9.44957
$S-a$	=	36° 45′ 43″	sin	=	9.77706
				2)	19.31924
			log sin ½ H. A.	=	9.65962
			L. App. T., Apr. 26	=	$3^h\ 37^m\ 23^s$ P. M.
			Eq. of T.	=	− $2^m\ 12^s$
			L. M. T., Apr. 26	=	$3^h\ 35^m\ 11^s$ P. M.
Fig. 14			Or, Apr. 25	=	$27^h\ 35^m\ 11^s$ P. M.
			G. M. T., Apr. 25	=	$15^h\ 41^m\ 13^s$ P. M.
			Diff.	=	$11^h\ 53^m\ 58^s$
			Long. D	=	178° 29.5′ E

Having determined the four positions, plot them on the chart, Fig. 15. Connect A and B by a straight line; this will be the first Sumner line. Similarly, connect C and D; this will give the second Sumner line. Move the first line forwards parallel with itself a distance $a\,b$ equal to

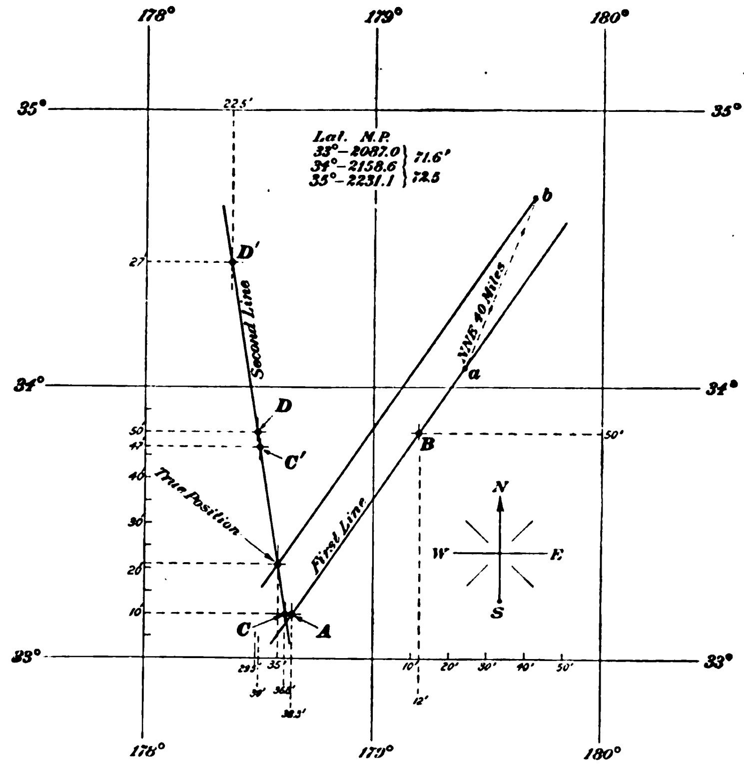


FIG. 15

the run between observations (N N E, 40 mi.). The point of intersection between this transferred line and the second Sumner line is the true position of the ship at the second observation; namely, latitude 33° 21′ N, and longitude 178° 35′ E. Ans.

16. In the foregoing solution, it will be noticed that the same assumed latitudes are used in the computation of both Sumner lines, although the ship has changed her latitude between the observations. It would seem that an allowance

should be made for the change in latitude, due to the run in the interval. This, however, is not essential so long as the change in latitude does not exceed, to any extent, the distance between the two assumed latitudes. If the run in the interval is nearly north or south, allowance may be made for the change and the longitude computed with the value of the latitudes thus found; but, the resulting line will differ slightly or not at all from the one determined by using the latitudes assumed for the first line. Therefore, it is more convenient to use the same latitudes for both lines because the computations are shorter and fewer logarithms are used. To show that the lines will coincide, the second line will be computed with latitudes that have been corrected for the run between sights. Since the latitude by account at the first observation is 33° 30′ N and the course and distance run is N N E 40 mi., the latitude in at second observation is as follows:

Lat. by account, 1st Obs.	= 33° 30′ N
Course run, N N E; Distance run, 40 mi. } D. Lat.	= + 37′ N
Lat. by account, 2d Obs.	= 34° 7′ N

Assuming latitudes of 20′ on either sides, 33° 47′ and 34° 27′ are obtained for use in computing the second line, which will be designated $C'D'$.

a =	36° 53′ 6″		
p =	76° 34′ 33″	cosec =	0.01203
l =	33° 47′ 0″	sec =	0.08032
	2)147° 14′ 39″		
S =	73° 37′ 19″	cos =	9.45021
$S-a$ =	36° 44′ 13″	sin =	9.77681
			2)19.31937
		log sin ½ H. A. =	9.65968
		L. App. T., Apr. 26 =	$3^h\ 37^m\ 25^s$ P. M.
		Eq. of T. =	$-\ 2^m\ 12^s$
		L. M. T., Apr. 26 =	$3^h\ 35^m\ 13^s$ P. M.
		Or, Apr. 25 =	$27^h\ 35^m\ 13^s$ P. M.
		G. M. T., Apr. 25 =	$15^h\ 41^m\ 13^s$ P. M.
		Diff. =	$11^h\ 54^m\ 0^s$
		Long. C' =	178° 30′ E

$a =$	$36° 53' 6''$		
$p =$	$76° 34' 33''$	cosec =	0.01203
$l =$	$34° 27' 0''$	sec =	0.08375
	2) $147° 54' 39''$		
$S =$	$73° 57' 19''$	cos =	9.44152
$S - a =$	$37° 4' 13''$	sin =	9.78017
			2) 19.31747

log sin $\frac{1}{2}$ H. A. = 9.65873
L. App. T., Apr. 26 = $3^h 36^m 55^s$ P. M.
Eq. of T. = $- 2^m 12^s$
L. M. T., Apr. 26 = $3^h 34^m 43^s$ P. M.
Or, Apr. 25 = $27^h 34^m 43^s$ P. M.
G. M. T., Apr. 25 = $15^h 41^m 13^s$ P. M.
Diff. = $11^h 53^m 30^s$
Long. D' = $178° 22.5'$ E

It should be noted that when these points C' and D' are plotted on chart, Fig. 15, they both lie along the line $C D$; hence, the resulting Sumner line will coincide exactly with the line previously computed. Therefore, from the result shown it is not essential to allow for the change in latitude due to the run made between the first and the second observation. In fact, if different values of latitude are used for the same altitude, and the longitude computed for each, the resulting points will all be located along the same line, or curve, of equal altitude, demonstrating very clearly the principles previously explained in connection with altitudes and lines of position.

Solution by Second Method.—The same example (Art. 15) will now be worked out according to the second or tangent method; that is, by calculating the longitude and the true azimuth at each observation and projecting the resulting Sumner lines on the chart. As the Greenwich mean time, the declination, the equation of time, and the true altitude at each sight are the same as before, these calculations need not be repeated here. In working both longitudes, the latitude in by account at each sight is used. The principal data of the example to be reworked were as follows: Greenwich mean time at first sight = April 25, $10^h 20^m 56^s$; at second sight = April 25, $15^h 41^m 13^s$. Latitude by account = $33° 30'$ N. Course and distance run between sights = N N E, 40 mi. Corrected equation of time at first sight = $2^m 9.3^s$ (−); at second sight = $2^m 11.7^s$ (−). Polar distance at first sight = $76° 38' 54''$; at second sight = $76° 34' 33''$. True altitude at first sight = $59° 24' 55''$; at second sight = $36° 53' 6''$.

$a = 59° 24' 55''$	. . . .	sec = 0.29344
$p = 76° 38' 54''$	cosec = 0.01190	
$l = 33° 30' \ 0''$	sec = 0.07889	sec = 0.07889
2) 169° 33′ 49″		
$S = 84° 46' 54''$	cos = 8.95881	cos = 8.95881
$S - a = 25° 21' 59''$	sin = 9.63186	
$S - p = \ 8° \ 8' \ 0''$	. . . .	cos = 9.99561
	2) 18.68146	2) 19.32675
	log sin $\frac{1}{2}$ H. A. = 9.34073	log sin $\frac{1}{2}$ Az. = 9.66337
	L. App. T., Apr. 26 = $10^h\ 18^m\ 44^s$ A. M.	$\frac{1}{2}$ Az. = 27° 26′
	Eq. of T. = − $2^m\ 9^s$	Az. = S 54° 52′ E
	L. M. T., Apr. 26 = $10^h\ 16^m\ 35^s$ A. M.	
	Or, Apr. 25 = $22^h\ 16^m\ 35^s$ P. M.	*First Line*
	G. M. T., Apr. 25 = $10^h\ 20^m\ 56^s$ P. M.	{N 35° 8′ E, S 35° 8′ W}
	Diff. = $11^h\ 55^m\ 39^s$	
	Long. = 178° 54′ 45″ E	

Now calculate the second line, using the latitude in at second observation; this is found from the first latitude by allowing for the run made in the interval. Thus,

Lat., 1st Obs. =	33° 30′ N
D. Lat. (N N E, 40 mi.) =	+ 37′ N
Lat., 2d Obs. =	34° 7′ N

$a = 36° 53' \ 6''$	. . . .	sec = 0.09700
$p = 76° 34' 33''$	cosec = 0.01203	
$l = 34° \ 7' \ 0''$	sec = 0.08202	sec = 0.08202
2) 147° 34′ 39″		
$S = 73° 47' 19''$	cos = 9.44589	cos = 9.44589
$S - a = 36° 54' 13''$	sin = 9.77849	
$p - S = \ 2° 47' 14''$	. . . .	cos = 9.99949
	2) 19.31843	2) 19.62440
	log sin $\frac{1}{2}$ H. A. = 9.65921	log sin $\frac{1}{2}$ Az. = 9.81220
	L. App. T., Apr. 26 = $3^h\ 37^m\ 10^s$ P. M.	$\frac{1}{2}$ Az. = 40° 28′
	Eq. of T. = − $2^m\ 12^s$	Az. = S 80° 56′ W
	L. M. T., Apr. 26 = $3^h\ 34^m\ 58^s$ P. M.	
	Or, Apr. 25 = $27^h\ 34^m\ 58^s$ P. M.	*Second Line*
	G. M. T., Apr. 25 = $15^h\ 41^m\ 13^s$ P. M.	{N 9° 4′ W, S 9° 4′ E}
	Diff. = $11^h\ 53^m\ 45^s$	
	Long. = 178° 26′ 15″ E	

The first position, latitude 33° 30′ N and longitude 178° 55′ E, is now plotted on the chart, Fig. 16, as is also the true bearing S 54° 52′ E. A line drawn through this position perpendicular to the bearing will produce the first Sumner line. Proceed similarly with the second position, and get the second Sumner line. From any point *a* on the first line, lay off the course and distance run between sights, and through the point *b* thus obtained draw a line parallel with the

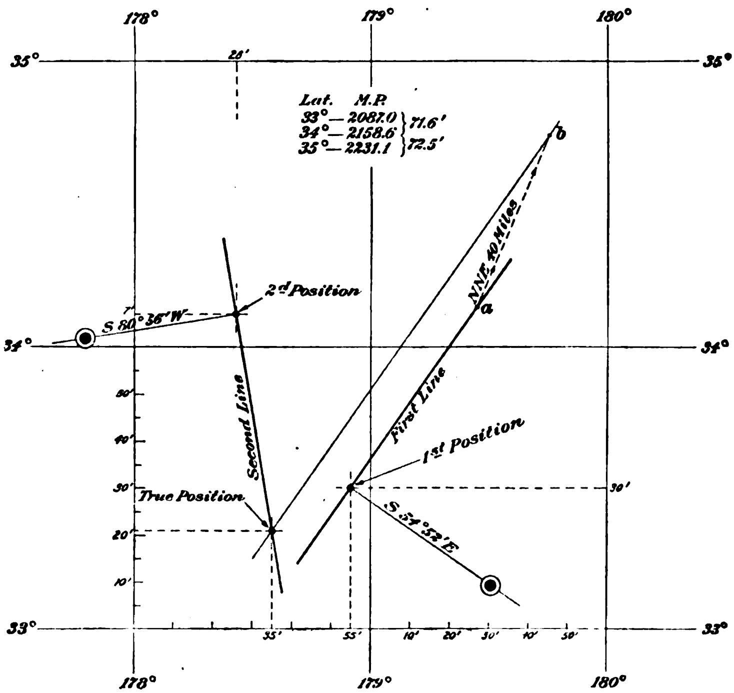


FIG. 16

first Sumner line. The intersection of this line with the second Sumner line is the true position of the ship at the second observation. By measurement on the chart, it will be seen that this position agrees exactly with that established by lines plotted on the chart shown in Fig. 15, the latitude and the longitude of each being 33° 21′ N and 178° 35′ E. Ans.

17. In the solution by the second method, the true azimuth is computed at each sight, according to the altitude-azimuth formula. In practice, however, the true azimuth is

usually found by inspection directly from the Azimuth Tables, which operation materially simplifies the process. For instance, in this case, instead of calculating the azimuth at first observation, it may be found by entering the Azimuth Tables with apparent time $10^h\ 20^m$ A. M., declination 13°, and latitude $33\frac{1}{2}$°, when, by interpolation, the corresponding azimuth is N 125° E, or S 55° E. At the second sight, the apparent time is $3^h\ 40^m$ P. M., latitude 34°, and declination 13°, the corresponding azimuth of which is N 99° W, or S 81° W. In the examples involving the computation of Sumner lines that appear throughout this Section, the true azimuth will be calculated by the altitude-azimuth formula.

EXAMPLE.—Early in the forenoon of May 15, 1899, an altitude of the sun's lower limb was observed and found to be 19° 32′. At the instant of measuring the altitude, the Greenwich date, according to chronometer, was May 15, $2^h\ 51^m\ 26^s$, the error of the chronometer being $1^m\ 12^s$ *slow*. The index error of sextant was − 2′ 11″, the latitude in, by dead reckoning, was 49° N, and the height of the observer's eye above the water-line was 31 feet. Later in the forenoon, and after having run true N W a distance of 42 miles, another observation of the sun's lower limb was taken, when its altitude was 56° 22′ 25″, the Greenwich date at that instant being May 15, $7^h\ 11^m\ 40^s$, and the error of the chronometer the same as at first observation. Required, the true position of the ship at second observation; also, find, by construction, an approximate value of the error in latitude at the first observation.

Computation for H. A. and Az. at first sight

SOLUTION.—

Chron.	=	$2^h\ 51^m\ 26^s$
Error (slow)	=	+ $1^m\ 12^s$
G. M. T., May 15	=	$2^h\ 52^m\ 38^s$

⊙ Decl., May 15	=	N 18° 53′ 0.7″	Change in 1^h	=	35.38″
Corr.	=	+ 1′ 42.6″			× 2.9^h
⊙ Corr. Decl.	=	N 18° 54′ 43.3″	Corr.	=	102.602″
		90° 0′ 0″	Or	=	1′ 42.6″
P. D.	=	71° 5′ 17″			

Eq. of T., May 15	=	$3^m\ 48.77^s$	Change in 1^h	=	0.019^s
Corr.	=	− $.05^s$			× 2.9^h
Eq. of T.	=	$3^m\ 48.72^s$ (−)	Corr.	=	$.0551^s$

Obs. Alt. $\underline{\odot}$ =	19° 32′ 00″
I. E. =	− 2′ 11″
	19° 29′ 49″
Dip =	− 5′ 27″
	19° 24′ 22″
⊙ S. D. =	+ 15′ 51″
	19° 40′ 13″
Par. Ref. =	− 2′ 33″
True Alt. =	19° 37′ 40″

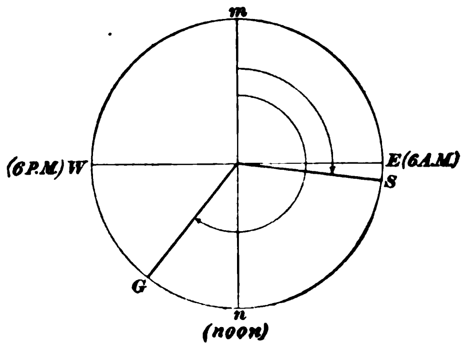


FIG. 17

a =	19° 37′ 40″	. . . .		sec =	0.02600
p =	71° 5′ 17″	cosec =	0.02410		
l =	49° 0′ 0″	sec =	0.18306	sec =	0.18306
	2) 139° 42′ 57″				
S =	69° 51′ 28″	cos =	9.53700	cos =	9.53700
$S - a$ =	50° 13′ 48″	sin =	9.88571		
$p - S$ =	1° 13′ 49″	. . . .		cos =	9.99990
			2) 19.62987		2) 19.74596

log sin ½ H. A. = 9.81493 log sin ½ Az. = 9.87298

L. App. T., May 15 = $6^h 33^m 51^s$ A. M. ½ Az. = 48° 17′

Eq. of T. = − $3^m 49^s$ ⊙ Az. = S 96° 34′ E

Fig. 17 { L. M. T., May 15 = $6^h 30^m 2^s$ A. M.
G. M. T., May 15 = $14^h 52^m 38^s$ A. M. }

Diff. = $8^h 22^m 36^s$

Long. = 125° 39′ W

First Line

{ N 6° 34′ W
S 6° 34′ E }

Computation for H. A. and Az. at second sight

Chron. =	$7^h 11^m 40^s$
Error (slow) =	+ $1^m 12^s$
G. M. T., May 15 =	$7^h 12^m 52^s$

⊙ Decl., May 15 =	N 18° 53′ 0.7″	Change in 1^h =	35.38″
Corr. =	+ 4′ 14.7″		× 7.2^h
⊙ Corr. Decl. =	N 18° 57′ 15.4″	Corr. =	254.736″
	90° 0′ 0″	Or =	4′ 14.7″
P. D. =	71° 2′ 45″		

Eq. of T., May 15 = $3^m\,48.77^s$	Change in 1^h = 0.019^s
Corr. = − $.14^s$	$\times\,7.2^h$
Eq. of T. = $3^m\,48.63^s$ (−)	Corr. = $.1368^s$

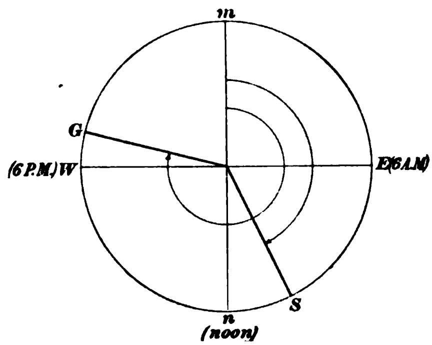


FIG. 18

Obs. Alt. $\underline{\odot}$ = 56° 22′ 25″
I. E. = − 2′ 11″
56° 20′ 14″
Dip = − 5′ 27″
56° 14′ 47″
$\odot$ S. D. = + 15′ 51″
56° 30′ 38″
Par. Ref. = − 0′ 33″

a = 56° 30′ 5″			sec =	0.25811
p = 71° 2′ 45″	cosec =	0.02421		
l = 49° 30′ 0″	sec =	0.18746	sec =	0.18746
2) 177° 2′ 50″				
S = 88° 31′ 25″	cos =	8.41107	cos =	8.41107
$S - a$ = 32° 1′ 20″	sin =	9.72448		
$S - p$ = 17° 28′ 40″			cos =	9.97947
		2) 18.34722		2) 18.83611
	log sin ½ H. A. =	9.17361	log sin ½ Az. =	9.41805
	L. App. T., May 15 =	$10^h\,51^m\,23^s$ A. M.	½ Az. =	15° 11′
	Eq. of T. =	− $3^m\,49^s$	$\odot$ Az. =	S 30° 22′ E

Fig. 18 {L. M. T., May 15 = $10^h\,47^m\,34^s$ A. M.; G. M. T., May 15 = $19^h\,12^m\,52^s$ A. M.}
Diff. = $8^h\,25^m\,18^s$
Long. = 126° 19.5′ W

Second Line
{N 59° 38′ E; S 59° 38′ W}

The latitude for the second calculation is obtained by entering the Traverse Table with the course and distance run in the interval between the observations. The difference in latitude thus found is 29.7′, or 30′, nearly, and when applied to the latitude in at first observation will give the latitude at second observation as 49° 30′ N. Now, in order to find the true position of the ship at the second observation, mark on the chart, Fig. 19, the computed longitudes on their respective latitudes, and through the positions thus obtained draw the Sumner lines (each perpendicular to the true azimuth). The line $t\,u$ will then represent the first, and $s\,v$ the second, Sumner line. From any point a on the first line, lay off in a northwesterly direction a line $a\,b$ 42 mi. long,

according to the latitude scale, and through the extremity b of that line draw another line $t_1\, u_1$ parallel to $t\, u$. The point c where this line intersects the second Sumner line $s\, v$ is the true position of the ship at the second observation (= Lat. 49° 27.5′ N and Long. 126° 24′ W, approximately). To show the actual position of the ship when the first observation was made, draw from c a line parallel to $a\, b$; the point d where this line intersects the first Sumner line $t\, u$ was the position of

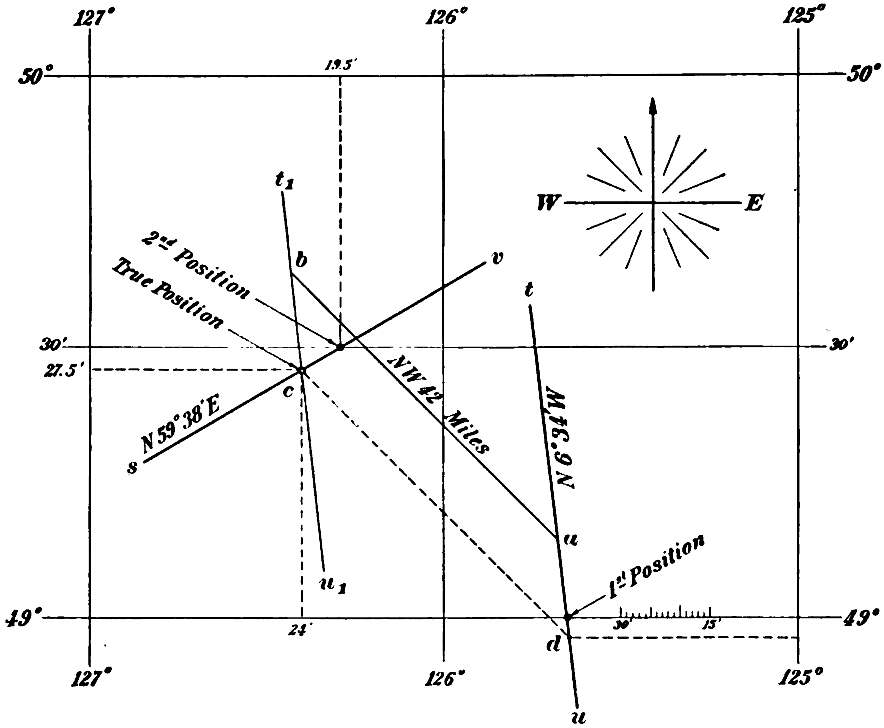


FIG. 19

the ship at the morning observation. Hence, the latitude by dead reckoning was about $2\frac{1}{2}'$ to the north in error, but on account of the sun's easterly bearing, the error in longitude amounted to only a fraction of a minute. Ans.

18. Graphical Examples Showing Application of Sumner's Method.—The usefulness of the Sumner method, when approaching a coast line, is shown by the following graphical examples:

Suppose that you are about to make a coast that lies to the north, the harbor at *H*, Fig. 20, being your destination. On account of misty weather, you are somewhat uncertain of your position, having been unable to get observation of the sun or any other body during the preceding day. It is 6 A. M., and you expect to reach the coast before 11 A. M. You proceed cautiously under short sails, or reduced speed, using the lead frequently, and at 8 A. M. you are fortunate enough to get a time sight of the sun, the true bearing of which is E S E. This gives you a Sumner line *t u* running N N E,

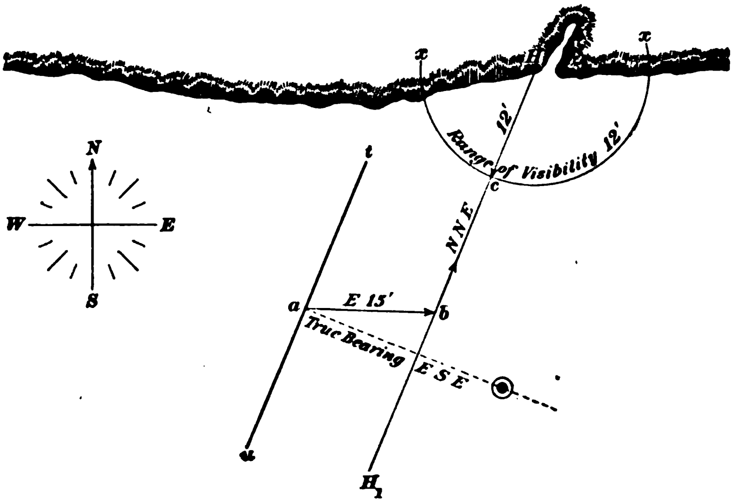


FIG. 20

and the ship's position on that line, according to the latitude by dead reckoning, is at *a*. Now, from *H* draw a line $H H_1$ parallel to the Sumner line, and from *a* draw a line *a b* nearly parallel to the coast line, or true east, until it intersects $H H_1$ at *b*. Measuring the length of *a b*, you find it to be 15 miles. Then put your ship on a course true east, and after having covered a distance of 15 miles, change the course to N N E. The ship will then be on the line $H H_1$ and heading directly for her destination, and by following this course you are sure to make the harbor at *H*, even if the latitude by account should be somewhat out.

Assuming the chronometer to be correct, the only thing that can put you wrong in this case will be a current, either unknown or insufficiently allowed for. Having steered the course N N E for about 2 hours, the weather in the meantime having cleared, the lighthouse at H appears on the horizon, its range of visibility, according to chart, being 12 miles. You will then know that you are on the circle $x\,x$, and may verify your position by taking a bearing of the lighthouse.

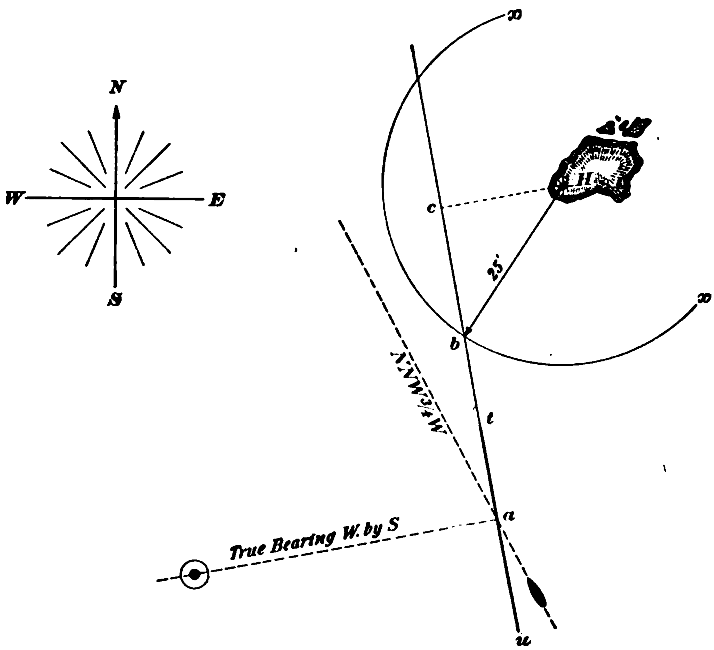


FIG. 21

If no current has interfered with your sailing since the time sight at 8 A. M., the position of the ship should be at c.

19. Again, suppose that on a passage between two ports you wish to verify your exact position (and error of chronometer) by the bearing of a well-known mountainous island that lies in your course, and on which there is a lighthouse, the range of visibility of which is 25 miles. Uncertain of

your position, you do not wish to get too close, since rocks and reefs are plentiful around the island and, hence, you are steering a course that will do away with all possibility of an encounter with these obstacles. The weather is cloudy, having been so all day and the previous night, thus preventing astronomical observations of any kind. A few minutes before sunset, however, there is a partial clearance of the western sky, which enables you to make an observation for longitude by a sunset sight, the true bearing of the sun at the time of setting being W by S. The Sumner line $t\,u$, Fig. 21, resulting from this observation, accordingly runs in a N by W and S by E direction, and from the latitude in by dead reckoning the position of the ship is found to be at a.

By the position of this point a you will know that your present course, N N W $\frac{3}{4}$ W (see dotted line), will not take you within the range of visibility of the light H on the island, as desired, but by following the Sumner line $t\,u$, or its continuation, your object will be accomplished. Accordingly, you change the course to N by W and sail along the Sumner line. Some 3 hours later the light becomes visible. You know, then, that your position is at b, where the continuation of the Sumner line intersects the circle $x\,x$ representing the range of visibility of H. Pursuing the same course, N by W, you will be at c when the light is abeam, and in case the run from b to c is accurately measured by the log, and not interfered with by currents your exact distance at c from the lighthouse H can be readily found by solving the right triangle $b\,c\,H$ for $H\,c$, either by calculation or by means of the Traverse Tables, two sides and an included angle being known. Many similar examples could be shown, but those just given will perhaps suffice.

20. Remarks on Sumner's Method.—From the foregoing examples and explanations, the beginner will readily understand and grasp the whole theory and working of Sumner's method, and at the same time realize that by judicious use, this method may, under various conditions and circumstances, be employed with great advantage in fixing

the position of a ship at sea. The various applications of Sumner's method in navigation are practically unlimited. Thus, in approaching a coast line, for instance, a Sumner line combined with a chain of sounding or a single bearing of a distant light, or other known object, will accurately fix the ship's position. It should be remembered that a Sumner line may be had from any kind of observation, whether it be for latitude or for longitude, provided the true bearing of the observed object is noted at instant of measuring the altitude. Thus, the Sumner line resulting from a meridian altitude of the sun will run true east and west, and may be combined with a second line obtained by a time sight, taken either 2 or 3 hours later or by one that was taken in the forenoon.

21. An ex-meridian observation for latitude taken on either side of the meridian may likewise be used in establishing Sumner lines, by noting the azimuth of the observed body or by assuming two longitudes. In either case, a valuable line of position is obtained. As an illustration, reference may be made to a case that occurred a few years ago of a sailing vessel approaching the coast of North Carolina. Having been without sights for several days, her position was very uncertain and her captain somewhat worried, especially in the presence of signs of approaching bad weather. About half-past one in the afternoon, one of the officers succeeded in getting a sight of the sun. This, however, did not console the captain, because he considered the sight of no value, since it was too late for latitude and too early for longitude. Nevertheless, the sight was worked out by the *M* and *N* method, using two assumed longitudes and thus obtaining two latitudes. This gave a Sumner line running about W N W and E S E. Plotted on the chart, this line passed 20 miles south of Cape Henry. The vessel was accordingly hauled up, and after having made 20 miles of northing, was put on a course W N W, after which Cape Henry was picked up right ahead, and the vessel got in port just in time to avoid a severe gale.

22. Probably the most valuable point of intersection is obtained from a Sumner line of a star or a planet at morning twilight crossed by a subsequent line of the sun; or, from a line derived from the sun in the latter part of the afternoon crossed by a second line from a star or a planet at evening twilight, the direction of the lines in each case being such as to establish a good and defined point of intersection.

When establishing a Sumner line from the observation of a star if the declination is greater than 23° and the altitude higher than 60° its azimuth cannot be found from the Azimuth Tables but must be obtained either by compass or by calculation. If the errors of the compass by which the bearing is taken are uncertain it is better to calculate the azimuth.

Sumner lines resulting from simultaneous observation of two stars or a star and a planet separated in azimuth about 90° also give a valuable point of intersection. As stated before, however, if the longitudes from such observations do not agree, it shows that the latitude used is in error; if they do agree it is evident that the lines of position need not be plotted on chart. Such observations should necessarily be made by two observers, each measuring the altitude of his particular star at the same moment, if possible. If for some reason this cannot be done, each sight should be worked out independently and the lines plotted as usual. In the example that follows, two stars of the first magnitude are selected. The resulting longitudes show that the latitude by account was very nearly correct.

EXAMPLE.—On March 19, 1899, at about 8:30 P. M., simultaneous observations were taken of the stars Regulus (α Leonis) and Aldebaran (α Tauri). The sextant altitude of the former was 46° 19′ 20″ east of the meridian, and that of the latter was 34° 3′ west of the meridian. At the instant that these observations were made, the chronometer indicated $11^h\ 1^m\ 34^s$, its error on Greenwich mean time being $5^m\ 21^s$ slow. Height of observer's eye above sea level = 29 feet. Index error of sextant = + 4′ 10″. Latitude and longitude by dead reckoning = 50° 5′ N and 40° 33′ W. Find, by Sumner's method, the true position of the ship at the time of observation.

Computation for H. A. and Az. of Regulus

Solution.— Approx. L. M. T., Mch. 19 = $8^h\ 30^m\ 0^s$
Long. in time (W) = $2^h\ 42^m\ 12^s$
Approx. G. M. T., Mch. 19 = $11^h\ 12^m\ 12^s$

Chron. = $11^h\ 1^m\ 34^s$
Error (slow) = + $5^m\ 21^s$
G. M. T., Mch. 19 = $11^h\ 6^m\ 55^s$
R. A. M. S. = $23^h\ 49^m\ 5^s$
G. Sid. T., Mch. 19 = $34^h\ 56^m\ 0^s$
Or, Mch. 20 = $10^h\ 56^m\ 0^s$

Sid. time, G. M. N. = $23^h\ 47^m\ 15.5^s$
Corr. for $11^h\ 7^m$ = $1^m\ 49.6^s$
R. A. M. S. = $23^h\ 49^m\ 5.1^s$
✳ Decl. = N 12° 27′ 35″
90° 0′ 0″
P. D. = 77° 32′ 25″
✳ R. A. = $10^h\ 3^m\ 0^s$

Obs. Alt. ✳ = 46° 19′ 20″ E
I. E. = + 4′ 10″
46° 23′ 30″
Dip = − 5′ 17″
46° 18′ 13″
Rep. = − 54″

a = 46° 17′ 19″ . . . . sec = 0.16050
p = 77° 32′ 25″ cosec = 0.01035
l = 50° 5′ 0″ sec = 0.19269 sec = 0.19269
2)173° 54′ 44″
S = 86° 57′ 22″ cos = 8.72502 cos = 8.72502
$S - a$ = 40° 40′ 3″ sin = 9.81403
$S - p$ = 9° 24′ 57″ . . . . cos = 9.99411
2)18.74209 2)19.07232

log sin ½ H. A. = 9.37104 log sin ½ Az. = 9.53616
✳ H. A. = $1^h\ 48^m\ 43.5^s$ ½ Az. = 20° 6′
✳ R. A. = $10^h\ 3^m\ 0^s$ ✳ Az. = S 40° 12′ E

L. Sid. T., Mch. 20 = $8^h\ 14^m\ 16.5^s$
G. Sid. T., Mch. 20 = $10^h\ 56^m\ 0^s$
Diff. = $2^h\ 41^m\ 43.5^s$
Long. by Regulus = 40° 25.9′ W

First Line
$\left\{\begin{matrix}\text{N } 49° 48' \text{ E} \\ \text{S } 49° 48' \text{ W}\end{matrix}\right\}$

Computation for H. A. and Az. of Aldebaran

The observations being simultaneous, the Greenwich **sidereal time** is the same as in the previous solution, or Mch. 20, $10^h\ 56^m$.

✳ Decl. = N 16° 18′ 24″
90° 0′ 0″
P. D. = 73° 41′ 36″
✳ R. A. = $4^h\ 30^m\ 8^s$

Obs. Alt. ✳ =	34° 3′ 0″ W		
I. E. =	+ 4′ 10″		
	34° 7′ 10″		
Dip =	− 5′ 17″		
	34° 1′ 53″		
Ref. =	− 1′ 24″		
a =	34° 0′ 29″		sec = 0.08147
p =	73° 41′ 36″	cosec = 0.01783	
l =	50° 5′ 0″	sec = 0.19269	sec = 0.19269
	2)157° 47′ 5″		
S =	78° 53′ 32″	cos = 9.28480	cos = 9.28480
$S-a$ =	44° 53′ 3″	sin = 9.84861	
$S-p$ =	5° 11′ 56″		cos = 9.99821
		2)19.34393	2)19.55717
	log sin ½ H. A. =	9.67196	log sin ½ Az. = 9.77858
	✳ H. A. =	$3^h\,44^m\,12^s$	½ Az. = 36° 55′
	✳ R. A. =	$4^h\,30^m\,8^s$	✳ Az. = S 73° 50′ W
	L. Sid. T., Mch. 20 =	$8^h\,14^m\,20^s$	*Second Line*
	G. Sid. T., Mch. 20 =	$10^h\,56^m\,0^s$	N 16° 10′ W
	Diff. =	$2^h\,41^m\,40^s$	S 16° 10′ E
	Long. by Aldebaran =	40° 25′ W	

These Sumner lines, when plotted on the chart, Fig. 22, give the ship's true position as latitude 50° 5.5′ N and longitude 40° 25′ W, nearly. Ans.

It will be seen that the latitude used in the calculation was very nearly correct, and therefore the resulting longitudes agree within .9′. If the latitude used had been correct, the resulting longitudes would have agreed exactly. A knowledge of this fact will often save considerable time and trouble in determining the true position, since, when the longitudes calculated are the same, the latitude used was correct, and the required position is at once known without plotting any lines whatever.

23. Allowance for Variation and Deviation.—In case Azimuth Tables are not available and the bearing of the observed object is taken by compass, it is evident that in order to get the true bearing, allowance must be made both for the variation of the locality and for the deviation due to the direction of the ship's head when observing.

24. Plotting of Sumner Lines.—When plotting Sumner lines be careful not to soil or deface the chart. If

a regular chart is used, draw very light pencil lines and avoid the common practice of using the dividers in such a manner as to punch holes at every step. A good idea is not to use the chart for this purpose at all. Simply construct a mercatorial chart on a suitable sheet of paper and on a sufficiently large scale. This will give more satisfaction, and will save the regular chart from being worn out too soon. In fact it is not always possible to plot lines on a chart of small scale, and, moreover, a navigator may not

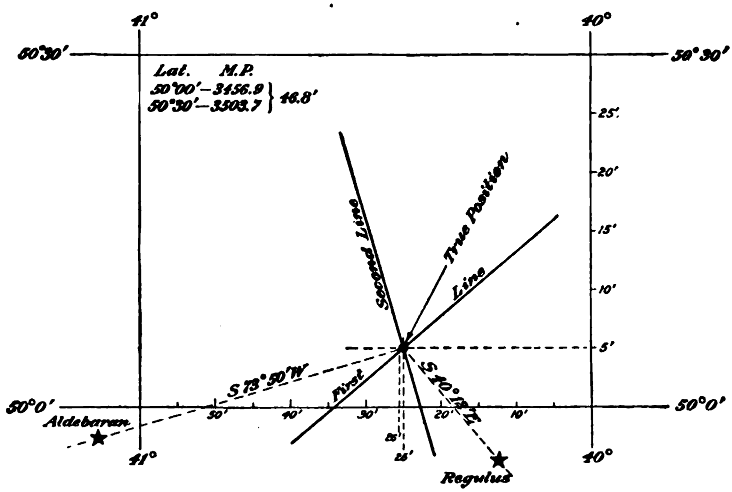


FIG. 22

always have sufficient table space at his command to spread out a good-sized chart.

25. Origin of Method.—The title of this excellent method, which should be known and practiced by every navigator, was given it in honor of Capt. Thomas H. Sumner, an American shipmaster, of Boston, Massachusetts, who first reduced it to a system, and subsequently proposed and published it in 1843. The discovery of this method, like many other discoveries, was made by mere accident. Captain Sumner was on a voyage from Charleston, South Carolina, to Greenock. When entering the Irish Channel, and uncertain of his position, having experienced several

days of heavy, foggy weather, he succeeded, through a partial clearing of the sky, in getting a time sight of the sun. The longitude thus found was of course unreliable, on account of the uncertainty of the latitude used. He accordingly assumed a second and a third latitude that would embrace the probable position, and calculated the longitude for each (using the *same altitude*). When the three positions were plotted on the chart, they were found to lie in a straight line, which, when extended, passed through Small's lighthouse. He then concluded that his position must be somewhere on that line, and shaped his course along the line in order to steer directly for the light. After a short run the light was sighted right ahead, thus confirming his conclusions.

JOHNSON'S METHOD

"DOUBLE CHRONOMETER METHOD, OR RULE FOR FINDING LATITUDE AND LONGITUDE BY TWO CHRONOMETER OBSERVATIONS"

26. Attention is here called to a method entitled by its author "Double Chronometer Method, or Rule for Finding Latitude and Longitude by Two Chronometer Observations." This method is popularly known as **Johnson's method,** after its author A. C. Johnson, of the British Navy, who first published it in a pamphlet entitled, "On Finding the Latitude and Longitude in Cloudy Weather and at Other Times." Briefly stated, the method consists in finding the true position of the ship by two separate observations for longitude, exactly as in Sumner's method, but without plotting the resulting lines of position on the chart, corrections being applied instead that allow for the run between observations and the error in latitude used in the computation. The method has been found especially useful in cloudy weather when there is a likelihood of the meridian altitude at noon being lost.

27. With the exception of the matter enclosed in parenthesis, the rules for working the method, as formulated by Johnson, are as follows:

"I. Let two chronometer observations (for hour angle) be taken at an interval of about an hour and a half or two hours, and let the first be worked out with the latitude by account at the time of observation.

"II. Let the latitude by account and the longitude thus obtained be corrected for the run of the ship in the interval between the observations, and let the second observation be worked with this corrected latitude. Name these longitudes (1) and (2).

"III. The bearing (true azimuth) of the sun at each observation is to be taken from an Azimuth Table.

"IV. Enter Table II (given in Johnson's book) with the latitude and bearings, and take from it two numbers (a) and (b), of which take the difference or sum, according as the bearings are in the same or adjacent quarters (quadrants) of the compass. The difference of longitude divided by this difference or sum gives the correction for the second latitude; and a and b multiplied by the correction for latitude give the corrections for the two longitudes.

"V. To apply corrections for longitude proceed as follows: When the observations are in the same or opposite quarters (quadrants) of the compass, allow both corrections to the east or both to the west. When the observations are in adjacent quarters of the compass, correct easterly longitude toward the west, and westerly longitude toward the east, in such manner as to make the two longitudes agree. If they do not agree, they show that the corrections have been wrongly applied; and herein we have a valuable safeguard against error, peculiar to this method only.

"VI. With either correction and the corresponding bearing (azimuth), find the name of the correction for latitude as in the preceding rule. Thus, suppose the correction for either longitude to be W and the corresponding bearing S W. Writing the letters N E under S W

S W
/
N E

we see that the letter opposite W is N, which is, accordingly, the name for the correction for latitude designated 2."

28. Applying Johnson's method to the second solution of the example of Art. **16,** the following results are obtained. The calculations for hour angles and azimuth will not be repeated here, only the latitudes, longitudes, and azimuths being used.

Lat. (1) =	33° 30′ N	Long. =	178° 55′ E
Corr. for run N N E, 40 mi. =	37′ N	Corr. for run N N E, 40 mi. =	19′ E
Lat. (2) =	34° 7′ N	Long. (1) =	179° 14′ E
1st Az. =	S 54° 52′ E	Long. (2) =	178° 26′ E
2d Az. =	S 80° 56′ W	Diff. =	48′

With Lat. (1) and 1st. Az., Johnson's Table II gives the number .85(*a*)
With Lat. (2) and 2d. Az., Johnson's Table II gives the number .19(*b*)

Azimuths in adjacent quadrants, take sum of (*a*) and (*b*) = 1.04

The difference in longitudes divided by this sum gives a correction for the second latitude; (*a*) and (*b*) multiplied by this correction gives the correction for the two longitudes. Thus,

$$\text{Corr. for Lat. (2)} = \frac{48}{1.04} = 46'$$

$$\text{Corr. for Long. (1)} = .85 \times 46 = 39.10'$$

$$\text{Corr. for Long. (2)} = .19 \times 46 = 8.74'$$

Applying these corrections according to the rules will give the following:

Long. (1) =	179° 14′ E	Long. (2) =	178° 26′ E
Corr. =	39′ W	Corr. =	9′ E
Long. in =	178° 35′ E	Long. in =	178° 35′ E

To find the name of the correction for latitude, write down either bearing—for instance, the first—and directly under it, write the name of the opposite quadrant, as shown below. Since the correction for longitude (1) is *W*, then the letter diagonally opposite, or *S*, is the required name, and the true latitude is then readily found. Thus,

S E
\
N W

Lat. (2) =	34° 7′ N
Corr. =	46′ S
Lat. true position =	33° 21′ N

It will be noticed that the latitude and the longitude of true position thus found by Johnson's method agree exactly with those found by plotting the Sumner lines in the solution of the example of Art. **16.**

29. Navigators that prefer Johnson's method to that of plotting Sumner lines on a chart, should get a copy of his pamphlet, already referred to, containing Table II for finding the two factors (*a*) and (*b*). However, if this table is not available, these numbers are readily obtained by a simple process of calculation as follows: To the secant of the latitude add the cotangent of the azimuth; the sum will be the logarithm for the required factor in each case; or,

$$(a) = \sec \text{Lat. } (1) \times \cot \text{Az. } (1)$$
$$(b) = \sec \text{Lat. } (2) \times \cot \text{Az. } (2)$$

EXAMPLE.—Find, by calculation, (*a*) and (*b*) in the preceding solution by Johnson's method.

SOLUTION.—

Lat. (1) 33° 30′ sec	= 0.07889	Lat. (2) 34° 7′	= 0.08202
Az. (1) 54° 52′ cot	= 9.84738	Az. (2) 80° 56′	= 9.20297
log (*a*)	= 9.92627	log (*b*)	= 9.28499
(*a*)	= .8439. Ans.	(*b*)	= .1927. Ans.

30. Remarks on Johnson's Method.—Johnson's method, so far as principles are concerned, is identical with Rosser's method of Double Altitudes, which, in turn, is a modification of Pagel's Double-Chronometer method, published in 1847. Johnson's method has an advantage over Sumner's method in that it can be used with confidence when observations are taken within a short interval, say, when the bearing of the observed body has changed only a point or less in azimuth, in which case the resulting Sumner lines would run nearly together, making a very uncertain point of intersection. The rules given by Johnson in regard to application of corrections are not always readily comprehended by a beginner, who goes by rules without giving thought to the cause and effect on which the rules are based. But, having studied Sumner's method and thus bearing in mind the direction in which the lines of position run in each case, and the run made by the ship in the interval, these rules should be easily understood by anybody. In each case of using Johnson's method, a good idea would be to draw on a piece of paper, roughly and

without any attempt at accuracy, the lines of position for each observation. Such a sketch would help in fixing the true position of the ship and would give a better idea of the proper way in which to apply the corrections.

EXAMPLES FOR PRACTICE

1. On June 30, 1899, at about 2:15 P. M., the observed altitude of the sun's lower limb was 54° 30′ 10″. The chronometer time at the instant of observation was June 30, $3^h\,38^m\,22^s$, its error on Greenwich mean time being $2^m\,15^s$ slow. Again, at about 5:30 P. M. on the same day, when the chronometer indicated $7^h\,8^m\,4^s$, another altitude of the sun's lower limb was measured and found to be 21° 48′. The vessel did not change her position between the observations, and her latitude in by account was 47° 50′ N. Index error = + 2′ 30″. Height of eye = 19 feet. Find, by Sumner's method, the true position of the vessel.

Ans. $\begin{cases} \text{Lat. } = 49° 20′ \text{ N} \\ \text{Long. } = 24° 1′ \text{ W} \end{cases}$

2. In the afternoon of September 29, 1899, when the chronometer indicated $9^h\,17^m\,58^s$, the sextant altitude of the sun's lower limb was 36° 28′ 40″. About 3 hours later in the afternoon, after having run true E $\frac{1}{4}$ N a distance of 43 miles, a second altitude of the sun's lower limb was observed and found to be 18° 34′ 15″, and the chronometer reading at this instant being $11^h\,53^m\,56^s$. The height of the observer's eye at both observations was 34 feet, the index error + 2′ 57″, and the chronometer error on Greenwich mean time $8^m\,14^s$ slow. At the first observation, the ship's latitude by dead reckoning was 48° 15′ N. The longitude was very uncertain, although it was estimated at 123° W. Find, by Sumner's method: (*a*) the true position at the second observation; (*b*) the error in latitude and longitude of the supposed first position of the ship.

Ans. $\begin{cases} (a) \begin{cases} \text{Lat. } = 48° 37′ \text{ N} \\ \text{Long. } = 125° 35′ \text{ W} \end{cases} \\ (b) \begin{cases} \text{Error in Lat. } = 20′ \text{ S} \\ \text{Error in Long. } = 68.5′ \text{ E} \end{cases} \end{cases}$

3. At about 9:45 P. M. on May 19, 1899, the position of the ship, though very uncertain, was estimated to be 48° 20′ N and 138° 30′ W. At this time, the observed altitude of Jupiter's center east of the meridian was 30° 7′ 25″, and at the same time the measured altitude of the star Pollux (β Geminorum), when west of the meridian, was 23° 39′ 30″. The chronometer reading when these simultaneous observations were made was $18^h\,56^m\,46^s$, the error on Greenwich mean time being $9^m\,11^s$ fast. Height of eye = 33 feet. Index error = + 4′ 3″. Find, by Sumner's method of projection, the true position of the ship.

Ans. $\begin{cases} \text{Lat. } = 48° 7.5′ \text{ N} \\ \text{Long. } = 139° 24.7′ \text{ W} \end{cases}$

CHRONOMETER ERROR BY ASTRONOMICAL OBSERVATIONS

SIMPLE METHODS OF DETERMINING BY OBSERVATIONS THE ERROR AND RATE OF THE CHRONOMETER

31. First Considerations.—When considering the method of determining the correct Greenwich mean time, it was seen that by applying the original error and accumulated rate to the time actually indicated by the chronometer, the correct Greenwich mean time at any required moment could be found. With an accurate value of the error and the rate of the chronometer, full confidence may, of course, be placed in the result. But, although implicit confidence may be placed in the original error, there is no security that the daily rate may not have changed. It is important, therefore, whenever an opportunity presents itself to look into this matter and, instead of taking the invariability of the original rate for granted, to ascertain the rate from time to time anew. To do this efficiently, the navigator must wait until the ship arrives at some port where it is expected that she will remain for several days. The chronometer may then be brought ashore to some responsible maker for rating; but in cases where this is inconvenient, or in ports where no makers are to be found, the navigator must rely on his own resources for determining the rate of his chronometer.

32. Time Signals.—In ports where established time signals are given regularly, by means of either time balls dropped or guns fired at a given hour of local or Greenwich mean time, the determination of the chronometer error and daily rate is comparatively easy. The requirements then are to note the reading of the chronometer at the moment the

time signal is given on a certain day, and after an interval of 4, 6, or 10 days to repeat the observation. If the time indicated by the chronometer on both occasions is exactly the same, it is evident that the instrument has no rate; but, on the other hand, if the times differ, which is more likely to be the case, the daily rate is found by dividing the difference of readings by the number of days elapsed between the observations.

For instance, if the chronometer, on October 31, indicated $3^h\ 40^m\ 52^s$ when the time ball dropped, and on November 10, when a similar signal was given, indicated $3^h\ 41^m\ 11^s$, the differences between these readings, divided by the number of days in the interval (in this case 10), would give the daily rate of the chronometer. Thus,

$$\begin{aligned} \text{Chron., Oct. 31} &= 3^h\ 40^m\ 52^s \\ \text{Chron., Nov. 10} &= 3^h\ 41^m\ 11^s \\ \hline \text{Diff.} &= 0^h\ \ 0^m\ 19^s \\ \text{Daily rate} &= \tfrac{19}{10} = 1.9^s \text{ gaining} \end{aligned}$$

33. It is evident that the error of the chronometer can also be determined by similar observations. For instance, if the time signal at a port in longitude 75° W is given at local mean noon, the chronometer should indicate exactly 5^h P. M. at the moment the signal is given. Similarly, if this signal is given at local mean noon at a port in longitude 75° E, the chronometer should indicate exactly $(12^h - 5^h =)$ 7^h A. M. If the chronometer does not indicate the correct time, as just stated, the difference will be the error of the chronometer on Greenwich mean time.

In ports of the United States where time signals are given, the ball is hoisted 5 minutes before noon, standard time, and is dropped *exactly at noon* in conformity with a telegraphic time signal received from the United States Naval Observatory at Washington, D. C. Should the ball, through any accident, be dropped *before* the exact instant of noon, it will be hoisted again immediately and kept up until 5 minutes after noon $(12^h\ 5^m)$, and then slowly lowered. Should the ball fail to drop on the instant at noon, it will be

kept mastheaded until 5 minutes after noon, and then slowly lowered as before.

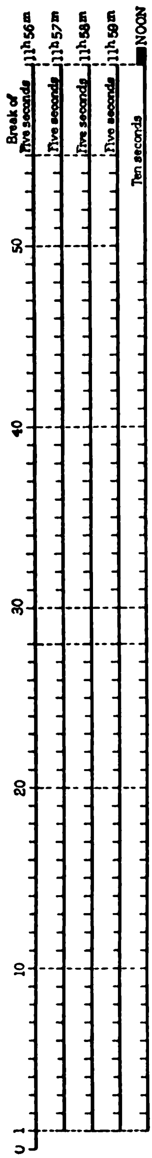


Fig. 23

34. Telegraphic Time Signals. Telegraphic time signals are sent out at noon daily, except Sundays and holidays, by the United States Naval Observatory. The entire series of noon signals sent out over the wires is shown graphically in Fig. 23. This figure shows the signals as they are recorded on a chronograph, where a pen that is actuated by an electromagnet, so as to make a jog at every tick of the transmitting clock, draws a line on a sheet of paper moving along at a uniform rate beneath it. The electric connections of the clock are such as to omit certain seconds, as shown by the breaks in the record. These breaks enable any one that is listening to a sounder in a telegraph or telephone office to recognize the middle and end of each minute, especially the end of the last minute, when there is a longer interval that is followed by the noon signal. During this last long interval, or 10-second break, those in charge of time balls and of clocks that are corrected electrically at noon throw their local lines into circuit so that the noon signal drops the time balls and corrects the clocks.

35. This series of noon signals is sent continuously over the wires all over the United States for an interval of 5 minutes immediately preceding noon. Shortly before noon, the transmitting clock at the Naval Observatory that sends out the signals is corrected very accurately from the mean of three standard clocks that are rated by star sights with a meridian transit

instrument. The noon signal is seldom in error to an amount greater than $\frac{1}{10}$ or $\frac{2}{10}$ second, although $\frac{1}{10}$ second more may be added by the relays in use on long telegraph lines. Electric transmission over a continuous wire is practically instantaneous. For time signals at other times than noon, similar signals can be sent out by telegraph or telephone from the same clock that sends out the noon signal.

Clocks in business houses, hotels, and schools, when electrically controlled, are thrown into circuit with the local telegraph lines and are corrected electrically at noon. Navigators that happen to be at such places when the time signals are being received can find with ease and certainty the error of a chronometer on the standard time being received, by noting the chronometer face when the signal is made. The difference between the chronometer face and the time of the signal will be the error on that time. The error on Greenwich mean time may be obtained by applying to this error the proper difference of longitude.

36. At the present day, time-signal establishments are found in nearly every port and harbor of commercial importance, but at places where no such facilities are available, the navigator is obliged to find some other means of determining the error and rate of his chronometer. Two methods for this purpose will be considered here; namely, by a *single altitude of the sun or a star*, and by *equal altitudes of a star*. In each of these methods, it is necessary that the latitude and longitude of the place of observation be *accurately* known.

37. To Find the Error and Rate of the Chronometer by a Single Altitude.—The method of finding the error and rate by a single altitude of the sun or a star consists simply in finding the local mean time, at the place of observation, by a time sight of the sun or a star, and from this the Greenwich mean time by applying the longitude in time. The difference between the Greenwich mean time thus found and the Greenwich time indicated by the chronometer at the instant of measuring the altitude will be the

error of the chronometer on Greenwich mean time. By two such observations, taken at an interval of a few days, the respective errors are compared, and the difference between these, divided by the number of days in the interval, will give the daily rate of the chronometer.

If, during the time between the two observations for error, the ship has changed her longitude considerably, it is evident that, in order to obtain accurate results, the difference in time between the places due to this difference of longitude should be allowed for, especially when the daily rate of the chronometer is believed to be large. Thus, the interval of time from noon, July 10, at a place in longitude 30° W to noon, July 22, in longitude 75° W would be 12 days *plus* 3 hours (the difference of longitude in time). Similarly, if the second place was 45° to the east of the first, the interval elapsed would be 12 days *minus* 3 hours.

Observations of the sun and stars for the purpose of finding the error and rate of the chronometer are made in a harbor or port, and in order to insure accuracy, the altitude or altitudes are usually measured in an artificial horizon either on board (if possible) or on shore. If made on shore, a watch or hack chronometer is used; this timepiece should be compared very carefully with the chronometer immediately before or after the observation is made.

When observations are made on shore, a suitable spot should be selected for the basin containing the mercury of the artificial horizon. This spot must be in a sheltered position, undisturbed by breezes and jars that might ripple the surface of the mercury. In order not to tire himself, the observer should sit on a low stool with his back supported, assuming a position as comfortable as circumstances will permit, and at the same time place himself so that he can see the image of the sun or the star reflected in the mercury. The person attending the hack chronometer, who is commonly known as the "time marker," should be stationed immediately behind the observer.

EXAMPLE.—On May 5, 1899, at about $10^h\ 45^m$ A. M., local mean time, the observed altitude of the sun's lower limb, measured in an

artificial horizon, was 129° 55′ 10″. Index error = + 4′ 16″. At the instant of observation the chronometer indicated $8^h\ 50^m\ 30^s$. Latitude of place = 35° 20′ N. Longitude = 29° 25′ E. Find the error of the chronometer on Greenwich mean time. Assuming the error of the same chronometer determined 10 days later, or on May 15, to be $1^m\ 39.3^s$ *fast*, find, also, its daily rate.

SOLUTION.—

L. M. T., May 5 =	$10^h\ 45^m\ 0^s$ A. M.	
Or, L. M. T., May 4 =	$22^h\ 45^m\ 0^s$	
Long. (E) in time =	$-\ 1^h\ 57^m\ 40^s$	
G. D., May 4 =	$20^h\ 47^m\ 20^s$	

$\odot$ Decl., May 5 =	N 16° 16′ 18.9″	Change in 1^h =	42.76″
Corr. =	− 2′ 16.8″		$\times\ 3.2^h$
$\odot$ Corr. Decl. =	N 16° 14′ 2″		136.832″
	90° 0′ 0″	Corr. =	2′ 16.8″
P. D. =	73° 45′ 58″		

Eq. of T. = $3^m\ 24.5^s$ (−) (By inspection)

Obs. double Alt. $\underline{\odot}$ =	129° 55′ 10″		
I. E. =	+ 4′ 16″		
	2)129° 59′ 26″		
Obs. Alt. $\underline{\odot}$ =	64° 59′ 43″		
$\odot$ S. D =	+ 15′ 53″		
	65° 15′ 36″		
Par. Ref. =	− 0′ 24″		
a =	65° 15′ 12″		
p =	73° 45′ 58″	log cosec =	0.01767
l =	35° 20′ 0″	log sec =	0.08842
	2)174° 21′ 10″		
S =	87° 10′ 35″	log cos =	8.69252
$S-a$ =	21° 55′ 23″	log sin =	9.57209
			2)18.37070
		log sin $\frac{1}{2}$ H. A. =	9.18539

L. App. T. =	$10^h\ 49^m\ 27.3^s$ (A. M. column)	
Eq. of T. =	$-\ 3^m\ 24.5^s$	
L. M. T., May 5 =	$10^h\ 46^m\ 2.8^s$ A. M.	
Long. (E) in time =	$-\ 1^h\ 57^m\ 40^s$	
Corr. G. M. T., May 5 =	$8^h\ 48^m\ 22.8^s$ A. M.	} at observation
G. M. T. according to Chron. =	$8^h\ 50^m\ 30^s$ A. M.	} at observation
Diff. = error =	$2^m\ 7.2^s$ *fast*.	Ans.
Error 10 da. later, May 15 =	$1^m\ 39.3^s$ *fast*	
Loss in 10 da. =	27.9^s	

$$\text{Daily rate} = \frac{27.9}{10} = 2.79^s\ \textit{losing}. \quad \text{Ans.}$$

38. To Find the Error and Rate of the Chronometer by Equal Altitudes of a Star.—The method of finding the error and rate by equal altitudes of a star consists in noting the chronometer time when a certain star S, Fig. 24, had the *same* altitude before and after its meridian passage. Since the declination of a star does not change in so short an interval, it is evident that half of the time elapsed between the two observations will give the exact time (according to the chronometer) when the star was on the meridian $m\,n$, and since

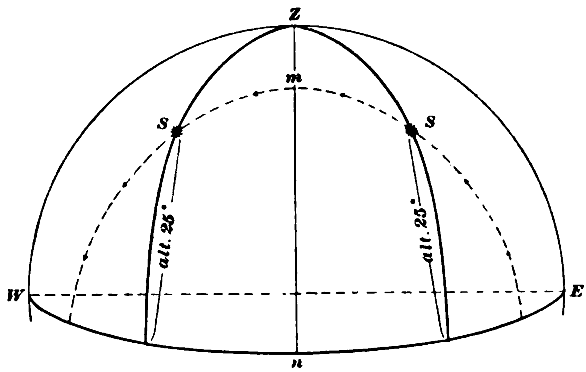


FIG. 24

the correct time of the star's meridian passage can be found independently of the chronometer, the difference between these times of transit will be the error of the chronometer.

39. The usual order of procedure for such observations is as follows: Having selected a star of the first magnitude whose position is at a considerable distance from the meridian, measure its altitude roughly with the sextant. Then advance the index mark so that it points to degrees and minutes without any fraction of a minute, and clamp the instrument. Wait until the star has attained the altitude indicated by the sextant; that is, until the two images of the star coincide in the artificial horizon. Note the indication of the chronometer at that instant. Then, without disturbing the index bar, wait until the star has attained the same altitude on the other side of the meridian, and note the chronometer

time at that instant. The mean of these times is the chronometer time of the star's transit. Compare this time with the correct mean time of the star's transit, as found according to instructions given in *Nautical Astronomy*, Part 2. The difference between these times gives the error of the chronometer.

By repeating the observation within an interval of a few days, the daily rate is readily deduced, as in the case of observations of the sun and of time signals.

EXAMPLE.—On May 19, 1899, at a place near Dumford Point, east coast of Africa (latitude 29° S and longitude 32° E), the chronometer indicated $5^h\,22^m\,40^s$ when the star Spica (α Virginis) had an altitude of 25° east of the meridian. When the star had attained the same altitude west of the meridian, the chronometer indicated $9^h\,30^m\,38^s$. Find the error of the chronometer on Greenwich mean time. On May 26, the error of the chronometer, as determined by similar observations, was found to be $4^m\,17.7^s$ fast. Find the daily rate.

SOLUTION.—First find the Greenwich mean time at transit by adding half the difference of chronometer times to the time when the star was east of the meridian. Thus,

Chron. =	$5^h\,22^m\,40^s$	when star was east of meridian
Chron. =	$9^h\,30^m\,38^s$	when star was west of meridian
	$2)\overline{14^h\,53^m\,18^s}$	
G. M. T. of transit =	$7^h\,26^m\,39^s$,	according to chronometer

Then find the correct Greenwich mean time of the star's transit. Thus,

✱ R. A. =	$13^h\,19^m\,53.5^s$
R. A. M. S., May 19 =	$3^h\,47^m\,45.3^s$
Approx. L. M. T. =	$9^h\,32^m\,8.2^s$
Long. (E) in time =	$2^h\,8^m\,0^s$
Approx. G. D., May 19 =	$7^h\,24^m\,8.2^s$
R. A. M. S., May 19 =	$3^h\,47^m\,45.3^s$
Table III, N. A., Corr. for $7^h\,24^m$ =	$1^m\,12.9^s$
Corr. R. A. M. S. =	$3^h\,48^m\,58.2^s$
✱ R. A. =	$13^h\,19^m\,53.5^s$
L. Sid. T. of transit =	$9^h\,30^m\,55.3^s$
Corr. (Table II, N. A.) =	$-\ 1^m\,33.5^s$
L. M. T. of transit =	$9^h\,29^m\,21.8^s$
Long. (E) in time =	$2^h\,8^m\,0^s$
Corr. G. M. T. at transit =	$7^h\,21^m\,21.8^s$
G. M. T. of transit, by Chron. =	$7^h\,26^m\,39^s$
Diff. = error on G. M. T., May 19 =	$5^m\,17.2^s$ *fast*. Ans.
Error on G. M. T., May 26 =	$4^m\,17.7^s$ *fast*
Gain in 7 da. =	59.5^s

Daily rate = $\frac{59.5^s}{7}$ = 8.5 *losing*. Ans.

40. In order to insure greater accuracy in determining the error of the chronometer by this method, several altitudes may be taken on each side of the meridian, say 20′ apart, as shown in Fig. 25, the chronometer being noted at each. The mean of these will then give a more accurate value of the time according to the chronometer when the star is on the meridian *m n*.

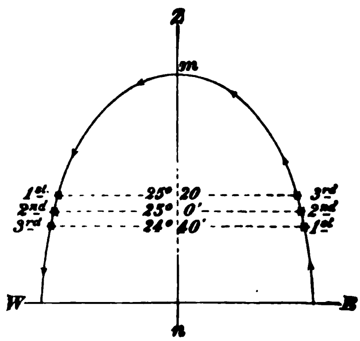


FIG. 25

It will be observed that by this method of equal altitudes any error arising from an imperfection of the sextant is altogether eliminated. Furthermore, the observer is not confined to observations of certain altitudes; he may select whatever altitude is convenient, giving preference to such altitudes as will insure an interval of about 3 or 4 hours between the observations, and to those altitudes where the motion of the star is most rapid or when the star is on or near the prime vertical.

41. Simplification of Method.—When applying the preceding method to stars, it is not necessary to observe the altitude on both sides of the meridian; instead, the second observation can be made the next night when the star attains the same altitude on the *same side of the meridian* as on the previous night. The reason for this is that, since the interval between two consecutive transits of the same star over the same meridian is uniformly $23^h\ 56^m\ 4.09^s$ of mean time, it follows that the return of any star to the same meridian is exactly $24^h - 23^h\ 56^m\ 4.09^s = 3^m\ 55.91^s$ earlier at every reappearance; and, moreover, on account of the strict uniformity of the diurnal motion, the star's return to a certain point or in fact to any point in its diurnal path is likewise $3^m\ 55.91^s$ earlier from night to night. Hence, if an altitude of a star is taken one night, and the chronometer noted, it will return to the same altitude, on the same side

of the meridian, $3^m\ 55.91^s$ earlier the following night, and 4 nights later it will return 4 times $3^m\ 55.91^s$ earlier, and so on. In other words, if the chronometer indicates $2^h\ 30^m\ 16^s$ on one night, when a certain star has an altitude of 24°, it should indicate $2^h\ 30^m\ 16^s - 3^m\ 55.91^s = 2^h\ 26^m\ 20.09^s$ the next night, when the star's altitude on the same side of the meridian is 24°. If not, the difference is the amount that the chronometer has gained or lost in a sidereal day. If several days have elapsed between the observations, it is evident that, by dividing the difference of the chronometer times by the number of days in the interval, the amount by which the quotient differs from $3^m\ 55.91^s$ will be the daily rate of the chronometer.

EXAMPLE.—On November 22, 1899, when the star Aldebaran had an altitude of 28° east of the meridian, the chronometer indicated $8^h\ 30^m\ 12^s$. On November 28, when the star had attained the same altitude on the same side of the meridian, the chronometer showed $8^h\ 6^m\ 40^s$. Find the daily rate.

SOLUTION.—Chron., Nov. 22 = $8^h\ 30^m\ 12^s$
Chron., Nov. 28 = $8^h\ 6^m\ 40^s$

Diff. in 6 da. = $23^m\ 32^s$

Diff. in 1 da. = $\dfrac{23^m\ 32^s}{6}$ = $3^m\ 55.33^s$ (Quotient)

True daily Diff. = $3^m\ 55.91^s$

Daily rate = $.58^s$ *gaining*. Ans.

It is evident that by this method of equal altitudes of a star on the *same* side of the meridian, the inconvenience of waiting a long time at unsuitable hours during the night for equal altitudes on both sides of the meridian is done away with. The observer may, instead, take observations on one night or evening and repeat it 2, 5, or 8 days afterwards. The result will be just as accurate and satisfactory.

42. At sea, when passing within sight of an island or point of land whose exact position is known, a navigator usually takes advantage of the opportunity thus presented to find the error of his chronometer by comparing the longitude

in, according to the chronometer, with the exact longitude, as determined by bearings. The difference in longitude between these positions, converted into time, will be the error of the chronometer.

TO FIND THE LONGITUDE BY EQUAL ALTITUDES TAKEN NEAR THE MERIDIAN

43. Explanation.—The method of finding the longitude by equal altitudes near noon is based on the assumption that by noting the time of the chronometer when the sun has equal altitudes on either side of the meridian, the mean of the times will be the time by the chronometer at the instant of apparent noon. The Greenwich mean time at apparent noon thus found is then compared with the local mean time at the same instant, and the difference between the two will be the longitude of the ship. The local mean time is obtained by applying the equation of time to the local apparent time at noon, which, of course, is equal to $0^h\ 0^m\ 0^s$. This method should be utilized only in *low latitudes*, and the altitudes should be taken a few minutes before and after apparent noon; the application of any correction, due to change of declination in the interval between observations, is then obviated, since the change is very small. Likewise, the correction for any change in latitude, under such circumstances, may be omitted. The procedure of finding the longitude by equal altitudes of the sun may be embodied in the directions that follow.

44. Directions.—Observe an altitude of the sun shortly before noon (usually as many minutes as there are degrees in the latitude in), and note carefully the reading of the chronometer. After the sun has crossed the meridian and begins to descend, watch the moment when it attains the same altitude and note the chronometer at that instant. Find the mean of the two times by dividing their sum by 2. Correct this time for any error of the chronometer. The result will be the Greenwich mean time at apparent noon. Find from the Nautical Almanac the equation of time; correct it

for the Greenwich mean time and apply it to the apparent time at noon ($= 0^h\ 0^m\ 0^s$). The result will be the local mean time at apparent noon. The difference between the local and the Greenwich time, converted into degrees, etc., will be the longitude of the ship at the instant of apparent noon.

EXAMPLE.—On August 2, 1899, when the estimated position of the ship was latitude 12° N and longitude 60° W, the sun was observed to have equal altitudes when near the meridian at the following times by the chronometer: Before noon, $4^h\ 10^m\ 25^s$; after noon, $4^h\ 30^m\ 23^s$. Find the longitude of the ship, the error of the chronometer on Greenwich mean time being $2^m\ 10^s$ fast.

SOLUTION.—

$$
\begin{aligned}
\text{Chron. before noon} &= 4^h\ 10^m\ 25^s\\
\text{Chron. after noon} &= \underline{4^h\ 30^m\ 23^s}\\
&\ 2)8^h\ 40^m\ 48^s\\
\text{Mid. time} &= 4^h\ 20^m\ 24^s\\
\text{Error (fast)} &= \underline{-\quad 2^m\ 10^s}\\
\text{G. M. T. at noon, Aug. 2} &= 4^h\ 18^m\ 14^s
\end{aligned}
$$

$$
\begin{aligned}
\text{Eq. of T., Aug. 2} &= 6^m\ 3.13^s & \text{Change in } 1^h &= 0.17^s\\
\text{Corr.} &= \underline{-\quad .73^s} & &\ \underline{\times\ 4.3^h}\\
\text{Corr. Eq. of T.} &= 6^m\ 2.4^s\ (+) & \text{Corr.} &= .731^s
\end{aligned}
$$

$$
\begin{aligned}
\text{L. App. T. at noon} &= 0^h\ \ 0^m\ \ 0^s\\
\text{Eq. of T.} &= \underline{+\ \ 6^m\ \ 2^h}\\
\text{L. M. T. at noon} &= 0^h\ \ 6^m\ \ 2^s\\
\text{G. M. T. at noon} &= \underline{4^h\ 18^m\ 14^s}\\
\text{Diff.} &= 4^h\ 12^m\ 12^s\\
\text{Long.} &= 63^\circ\ 3'\ \text{W.}\quad \text{Ans.}
\end{aligned}
$$

45. Remarks.—The longitude thus found is the longitude when the sun was on the meridian, and not that at the second observation. The simplicity of this method is evident, and by using it in combination with a meridian altitude, both latitude and longitude in at noon may be very conveniently found. The greatest accuracy is obtained when the latitude and declination are of the same name and nearly equal, especially in cases where the course in the interval has been true east or west, or nearly so.

46. When the course of the vessel is *not* east or west between the times of observation, and it is desired to apply a correction for change of latitude (which is proper when the

latitude is greater than the declination, or of a different name), this may be done, mechanically, as follows: If the vessel has sailed *toward* the sun, the second latitude should be *increased* by resetting the sextant as many minutes as there are miles in the difference of latitudes; if the vessel has sailed *from* the sun, the second altitude should be *decreased* in the same proportion. Thus, if the first altitude is 62° 24′ and the ship in the interval of time has changed her latitude 5′ *toward* the sun, the sextant, when taking the second observation, should be set to 62° 29′; if she had sailed *from* the sun, the instrument should be set to 62° 19′ before measuring the second altitude.

EXAMPLE 1.—On July 7, 1899, in latitude 24° N and longitude 45° W, approximately, equal altitudes of the sun's lower limb were observed when on either side of the meridian. Instead of taking the reading directly from the chronometer, a watch $3^h\ 12^m$ slower than the chronometer was used. The time indicated by the watch at observation before noon was $11^h\ 48^m\ 45^s$, and at observation after noon, $12^h\ 4^m\ 45^s$. Find the longitude of the ship at noon, assuming the error of the chronometer on Greenwich mean time to be $6^m\ 15^s$ fast.

SOLUTION.—

$$\begin{array}{rl}
\text{Watch before noon} = & 11^h\ 48^m\ 45^s \\
\text{Watch after noon} = & \underline{12^h\ \ 4^m\ 45^s} \\
& 2)23^h\ 53^m\ 30^s \\
\text{Mid. time by watch} = & 11^h\ 56^m\ 45^s \\
\text{Error of watch (slow)} = & \underline{+\,3^h\ 12^m\ \ 0^s} \\
\text{Chron. time} = & 3^h\ \ 8^m\ 45^s \\
\text{Error (fast)} = & \underline{-\qquad 6^m\ 15^s} \\
\text{G. M. T. at noon} = & 3^h\ \ 2^m\ 30^s
\end{array}$$

$$\begin{array}{rlrl}
\text{Eq. of T., July 7} = & 4^m\ 38.09^s & \text{Change in } 1^h = & 0.41^s \\
\text{Corr.} = & \underline{+\qquad 1.23^s} & & \underline{\times\, 3^h} \\
\text{Corr. Eq. of T.} = & 4^m\quad 39^s(+) & \text{Corr.} = & 1.23^s
\end{array}$$

$$\begin{array}{rl}
\text{L. App. T. at noon} = & 0^h\ \ 0^m\ \ 0^s \\
\text{Eq. of T.} = & \underline{+\qquad 4^m\ 39^s} \\
\text{L. M. T. at noon} = & 0^h\ \ 4^m\ 39^s \\
\text{G. M. T. at noon} = & \underline{3^h\ \ 2^m\ 30^s} \\
\text{Diff.} = & 2^h\ 57^m\ 51^s \\
\text{Long.} = & 44°\ 27'\ 45''\ \text{W. Ans.}
\end{array}$$

EXAMPLE 2.—On August 29, 1899, in latitude 14° 30′ N and longitude 150° 35′ E, by dead reckoning, equal altitudes of the sun's lower

limb were observed on either side of the meridian. The time by the watch at first observation was $11^h\ 42^m\ 32^s$, and at second observation, $12^h\ 8^m\ 56^s$. The watch was $2^h\ 5^m\ 40^s$ slow on chronometer time, and the error of the chronometer on Greenwich mean time was $5^m\ 3^s$ fast. Find the longitude in at noon.

SOLUTION.—

$$
\begin{aligned}
\text{Watch before noon} &= 11^h\ 42^m\ 32^s\\
\text{Watch after noon} &= 12^h\ \ 8^m\ 56^s\\
\hline
&\ 2)23^h\ 51^m\ 28^s\\
\text{Mid. time by watch} &= 11^h\ 55^m\ 44^s\\
\text{Error of watch (slow)} &= +\ 2^h\ \ 5^m\ 40^s\\
\hline
\text{Chron. time} &= 14^h\ \ 1^m\ 24^s\\
\text{Error (fast)} &= -\ \ \ 5^m\ \ 3^s\\
\hline
\text{G. M. T., at noon, Aug. 28} &= 13^h\ 56^m\ 21^s
\end{aligned}
$$

$$
\begin{aligned}
\text{Eq. of T., Aug. 29} &= 0^m\ 49.9^s & \text{Change in } 1^h &= 0.74^s\\
\text{Corr.} &= +\ \ \ 7.4^s & &\times\ 10^h\\
\hline
\text{Eq. of T.} &= 0^m\ 57.3^s(+) & \text{Corr.} &= 7.4^s
\end{aligned}
$$

$$
\begin{aligned}
\text{L. App. T. at noon, Aug. 29} &= 0^h\ \ 0^m\ \ 0^s\\
\text{Eq. of T.} &= +\ \ \ \ 0^m\ 57^s\\
\hline
\text{L. M. T. at noon, Aug. 29} &= 0^h\ \ 0^m\ 57^s\\
\text{Or, L. M. T. at noon, Aug. 28} &= 24^h\ \ 0^m\ 57^s\\
\text{G. M. T. at noon, Aug. 28} &= 13^h\ 56^m\ 21^s\\
\hline
\text{Diff.} &= 10^h\ \ 4^m\ 36^s\\
\text{Long.} &= 151^\circ\ 9'\ \text{E. Ans.}
\end{aligned}
$$

COMMENTS ON LONGITUDE BY LUNAR DISTANCES

47. Before the general introduction of the chronometer as a means of determining the Greenwich mean time at sea, a method commonly known as "Lunars" was resorted to for finding that time. The principles and leading features of this method are as follows: The moon in her motion around the earth is seen to change her distance continually in relation to celestial bodies lying near her path. The law of this motion of the moon is now (and has been for years) so thoroughly understood that her angular distance from any celestial body in her path at any future instant can always be predicted with strict accuracy. The angular distances of the moon from such bodies as are conveniently situated have

accordingly been computed and recorded in the Nautical Almanac for intervals of every 3 hours of Greenwich mean time. These distances, however, are true distances; that is, they are supposed to be measured from the center of the earth and to be unaffected by refraction. Hence, an observer at sea, wishing to find the Greenwich mean time, may measure the distance between the moon and some nearby body; but, before this measured distance can be compared with the true distance in the Nautical Almanac, it must be reduced to true, by a laborious and complicated mathematical process known as "Clearing the Distance." If the true distance thus found agrees exactly with the one recorded in the Nautical Almanac for some given hour at Greenwich, the Greenwich mean time at the instant of observation is found at once. But as such a coincidence rarely, if ever, happens, it becomes necessary to find, by proportion, the corresponding Greenwich mean time. The Greenwich mean time thus found is then compared with the local mean time computed from a time sight observed at the same instant as the lunar distance was measured, and the difference between these will give the longitude of the ship.

With the introduction of such excellency in chronometers as now exists, the method of determining the longitude by lunar observations has ceased to be of any practical importance, and at the present day it is very little used in the practice of navigation. Besides, being very laborious, this process is liable to error, which, while seemingly unimportant at the beginning, will seriously affect the final result. Thus, an error in the observed angular distance will produce very nearly thirty times that error in the resulting longitude. In addition, let it be understood that such extreme accuracy as is required in the measurement of lunar distances, in order to obtain a comparatively good result, can never be attained on board of a vessel at sea. This method is undoubtedly excellent for use on land, but at sea the result will seldom, if ever, justify the amount of time and labor spent on it. Its technical treatment is therefore omitted.

CROSSING THE 180TH MERIDIAN EAST OR WEST

48. From relations existing between longitude and time, it is evident that whenever a ship changes her longitude, her local time also changes at the rate of 4 minutes for every degree of longitude. This occurs in all latitudes. Thus, for instance, if a ship sails, or steams, to the eastward 6° of longitude during a day, her apparent noon will occur 24 minutes earlier each succeeding day; while if sailing to the westward, her apparent noon will be delayed 24 minutes each day.

When navigating in the Atlantic Ocean and the adjacent seas, no uncertainty should be experienced as to the correct determination of the ship's date. In the Pacific Ocean, however, when crossing the 180th meridian, conditions are materially altered. There the westerly longitude is changed to easterly, or vice versa, and at the same time the date is changed. The necessity for this is evident from the following.

49. Suppose that a ship sailing to the eastward arrives at longitude 180° E on Monday, January 15, at 1 o'clock A. M., or January 14, 13^h, astronomical time. The corresponding Greenwich astronomical time is then equal to $14^d\ 13^h - 12^h$ (= Long. E, in time) = January 14, 1^h, or January 14, 1 o'clock P. M., civil time. The ship has now gained 12 hours on the Greenwich time, and should the voyage be continued to the eastward without changing the date, an additional 12 hours will be gained when reaching the meridian of Greenwich. Consequently, the ship's date would be 24 hours, or 1 day, ahead of the Greenwich date, no matter if the time consumed in making the voyage were 2 months or 2 years. In other words, the ship's longitude on reaching the meridian of Greenwich would be 360° E, and if the correct date at Greenwich were Thursday, May 10, the ship's date, according to reckoning on board, would be Friday, May 11.

Similarly, if a ship sailing to the westward starts near longitude 0° and circumnavigates the earth without changing

the date at the crossing of the 180th meridian, the longitude being counted continually up to 360°, the ship will have lost 24 hours on the Greenwich time when returning to the meridian of Greenwich. In other words, the ship's longitude would be 360° W, and if the correct date at Greenwich were Thursday, May 10, the date, according to the ship's reckoning, would be Wednesday, May 9.

50. To further exemplify this curious relation between relative and absolute time, assume that two persons, A and B, start simultaneously from Greenwich on a trip around the world, A going to the eastward and B to the westward, each counting his days and date in the usual order. They both return to Greenwich on the same day, say, Wednesday, July 11, correct Greenwich date. Then, according to A's reckoning, his date is Thursday, July 12, and B's is Tuesday, July 10. Hence, according to the respective reckoning of each, the time occupied by A in making the same trip as B is 2 days longer than the time of B; yet they both returned to Greenwich on the same day.

51. In order to avoid complications of such nature, it is customary to change the date when crossing the 180th meridian according to the following rules:

When sailing eastward: repeat one day
When sailing westward: drop one day

To illustrate the first case, assume the ship to cross the 180th meridian (going east) on Sunday, July 15. Then the next day is also called Sunday, July 15, or 1 day is added by giving two successive days the same name and date.

In the second case, assume the ship to cross the 180th meridian (going west) on Sunday, July 15. Then the next day is called Tuesday, July 17, or 1 day is dropped by not counting Monday, July 16.

The correctness of this procedure is evident when it is remembered that

$15^d\ 13^h$ L. Ast. T. in Long. 180° E $=$ $15^d\ 1^h$ G. Ast. T.,
and $14^d\ 13^h$ L. Ast. T. in Long. 180° W $=$ $15^d\ 1^h$ G. Ast. T.;
whence, as a conclusion, the two quantities to the left are equal.

52. To avoid confusion, however, the beginner is advised to keep strict account of his Greenwich date. The advice on this matter given by Captain Lecky in his "Wrinkles on Navigation" is well worth remembering. It runs as follows: "The great point for the practical navigator to attend to is to hold on to his Greenwich date by the chronometer, otherwise he may make the not uncommon blunder of taking out of the Nautical Almanac elements for the wrong day, and so get adrift as to his true position. Here the marking of the chronometer face from 1 up to 24 hours would be of great service. As the dial is figured at present, there are no means of distinguishing the XII noon from the XII midnight; whereas, if marked as suggested, 24 hours would always refer to noon and 12 hours to midnight. If, however, a man, when winding his chronometer, were to take the trouble from the very beginning (of a voyage) to enter every day on a slip of paper kept in the case, the hour A. M. or P. M., day of the week, and day of the month (*Greenwich time*), of his doing so, he could not possibly get astray. When, by and by, he found his own or his ship's date differing from that of Greenwich, he would merely have to adopt the latter, whatever it might be. Thus, having passed the meridian of 180° E, on going to wind his chronometer at 8 o'clock on Tuesday morning, the 16th, he would find by his slip that at Greenwich it was 8 o'clock on Monday evening, the 15th, and would accordingly instruct his chief officer to consider the day as Monday over again, and so enter it in his log."

53. A short, handy rule for steamers plying across the Pacific Ocean, for instance between ports of the United States and the Philippine Islands, in determining the length of time of voyage is as follows: When going to the westward, add 1 day to the calculated time of passage and subtract from the sum the difference in longitude (in time) between the two ports. When going to the eastward, subtract 1 day and add to the remainder the difference in longitude.

MARCQ ST. HILAIRE'S METHOD
(PART 1)

DETERMINING LINES OF POSITION

PRINCIPLES INVOLVED

1. The New Navigation.—For some years a new and rather ingenious method of establishing lines of position has been practiced with much success in the French navy. It was proposed in 1875 by Admiral Marcq St. Hilaire and is known generally as the St. Hilaire method, though many refer to it as **the new navigation.** During recent years, this method has become widely known among navigators in the naval service and is steadily gaining in favor among officers in the merchant marine.

2. Comparison of Altitudes.—The method of St. Hilaire consists in computing the altitude of the observed body and comparing it with the measured altitude. The difference between the two altitudes, expressed in miles, is then laid off on the line of azimuth from the assumed position toward or from the observed body, according as the observed altitude is greater or less than the calculated altitude. Through the point thus established, a line is drawn perpendicular to the bearing of the celestial body; and this line is the required line of position corresponding in all particulars to the Sumner line found by the tangent or the chord method.

If a second altitude is observed after the azimuth of the body has changed and the altitude is again computed, a second line

of position is obtained, the intersection of which with the first line will be the true position of the ship.

3. Treatment of Run.—In case the ship has moved between the two observations, the first line is carried forwards according to course and distance run, the same as in Sumner's method. Thus if *a*, Fig. 1, is the assumed dead-reckoning position, *a S* the azimuth of the observed body *S*, and *a b* the difference between the observed and the calculated altitude, *m n* is the required line of position. In this case, it is assumed the calculated altitude is less than the observed altitude; hence, the line *m n* comes nearer the observed body by a distance equal to the difference in altitudes. After the ship has run from *a* to *c*, it is assumed a second altitude is measured of the

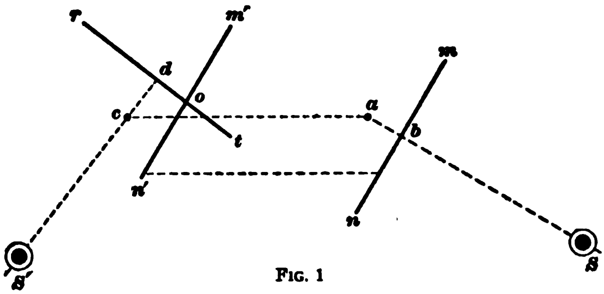


FIG. 1

body *S* whose line of bearing is now *c S'*. The calculated altitude at this sight is greater than that measured by an amount equal to *c d* and hence the resulting line of position *r t* comes farther from the observed body *S'*. The first line *m n* is now brought forwards, as shown, and its point of intersection *o* with the second line *r t* is the required true position of the ship at time of second observation.

4. Theory of St. Hilaire's Method.—The theory of St. Hilaire's method may be explained as follows: Suppose that *a*, Fig. 2, is the dead-reckoning position of the ship and *a b* the radius of uncertainty; in other words the position of the ship may be anywhere within a circle the radius of which is *a b*. Suppose further that *m n* is the line of position on which is the actual position of the ship. Then the middle point *c* on that line is the more probable place where the ship is, because *c* is

nearer any other point on *m n* than is *a* the dead-reckoning position. Hence, if the altitude calculated with latitude and longitude of *a* (dead-reckoning position) does not agree with the actual observed altitude of the body the resulting line of position from the actual altitude must be on either side of the dead-reckoning position at a distance equal to the difference in the two altitudes.

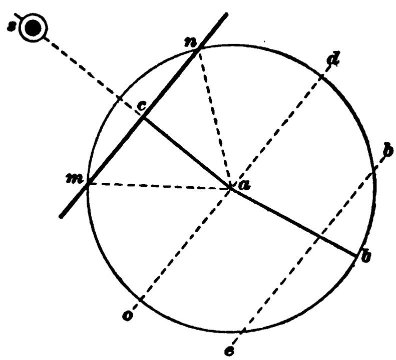


FIG. 2

5. Thus, if *a c* is the direction of bearing of the observed body *S*, and *o d* the line of position from altitude calculated with *a* as the assumed position; then, if the observed altitude is larger than the calculated altitude the true line of position must lie nearer the observed body than does *o d*; if the observed altitude is less, the line must lie on the other side of *o d*, or farther from the celestial body, as at *b e*. This is perhaps better illustrated in Fig. 3, where *s* represents the observed body, *a* the dead-reckoning position, and *d o* the corresponding position line. The lines *m n* and *b e* represent lines of position obtained from observed altitudes greater and less than the calculated altitude. The gist of St. Hilaire's method is therefore to compare the two altitudes and in this way find a line of position that, to all intents, agrees most nearly to the actual altitude, the azimuth, and the time at ship.

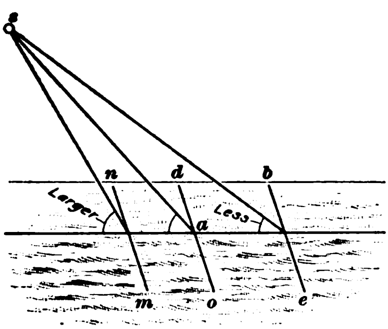


FIG. 3

6. **Advantages of St. Hilaire's Method.**—The most pronounced advantages of St. Hilaire's method are its exactness

and the generality of its application. It can be used practically without limitations to altitude, azimuth, or hour angle. In fact, it is available for application to sights at all hours whether of the sun or stars. The result will be as accurate from a sight near the prime vertical as from one near the meridian. But one exception may be stated and this applies equally well to all other methods by which lines of position are established. This exception is when the altitude of the observed body is greater than 85°. With so high an altitude, a straight line can no longer be considered as a substitute for a circle of altitude. Again, at very low altitudes, the effect of refraction is likely to render the measurement of altitudes unreliable. For these reasons it is not advisable to use the St. Hilaire method for altitudes below 10° or higher than 85°.

7. The Sine-Cosine Formula.—Various formulas are used in calculating the altitude in St. Hilaire's method, but the simplest is the one derived from the original formula

$$\cos \text{H. A.} = \frac{\sin a - \cos p \sin l}{\sin p \cos l}$$

Solving for sin a the formula becomes as follows:

$$\cos \text{H. A.} \sin p \cos l = \sin a - \cos p \sin l$$
$$\sin a = \cos \text{H. A.} \sin p \cos l + \cos p \sin l$$

But, $p = 90° - \text{declination}.$

Hence,

$$\sin a = \cos \text{H. A.} \cos d \cos l + \sin d \sin l$$

in which

a = altitude;
d = declination;
l = latitude;
H. A. = hour angle.

8. In the use of this formula, which is known as the *sine-cosine formula*, it is convenient to arrange the terms as follows: $A = \sin d \sin l$, $B = \cos \text{H. A.} \cos d \cos l$; whence, $\sin a = A + B$.

The factor A is found by picking out the number corresponding to the sum of log sin d and l in the Table of Logarithms of Numbers; B is found in a similar manner. The sum of A

and B will then be the natural sine of the required altitude found from the Table of Natural Sines and Cosines.

9. Another formula used for calculating the altitude is

$$\sin a = \cos (l-d) - 2 \cos l \cos d \sin^2 \tfrac{1}{2} \text{ H. A.}$$

in which the letters signify identical quantities as in the first formula.

10. To illustrate the application of both formulas, the example given in Art. **15** of *Sumner's Method* is worked out by each formula. It will be noticed that both natural and logarithmic functions are employed in the second formula.

EXAMPLE.—On April 26, 1899, about 10 A. M., an altitude of the sun's upper limb was measured and found to be 59° 42′ 50″. The chronometer reading at the instant of observation was $10^h\ 32^m\ 30^s$, April 25. Latitude by account was 33° 30′ N; longitude was 178° E. In the afternoon, after running true N N E, 40 miles, and when the chronometer showed $15^h\ 52^m\ 47^s$, April 25, a second observation of the sun's lower limb gave its altitude as 36° 39′ 50″. The error of the chronometer on the Greenwich mean time at both observations was $11^m\ 34^s$ fast. Height of eye = 28 feet. Index error of sextant = +3′ 41″. Azimuth at first sight was S 55° E; at second sight, S 81° W. Find the true position of the ship at the second observation.

FIRST SOLUTION.—

Computation for Altitude at First Sight

Find first $\frac{1}{2}$ H. A. from the data given in the example; thus,

$$\begin{aligned}
\text{G. M. T., Apr. } 25 &= 10^h\ 20^m\ 56^s \\
\text{Long. (178° E) in time} &= \underline{11^h\ 52^m\ \ 0^s} \\
\text{L. M. T., Apr. } 25 &= 22^h\ 12^m\ 56^s \\
\text{Eq. of T.} &= \underline{+\quad 2^m\ \ 9^s} \\
\text{L. App. T., Apr. } 25 &= 22^h\ 15^m\ \ 5^s \\
\text{H. A.} &= \ \ 1^h\ 44^m\ 55^s \\
\tfrac{1}{2}\text{ H. A.} &= 13°\ \ 6'\ 52''
\end{aligned}$$

Then find $(l-d)$ by subtracting declination from latitude and calculate the altitude by the formula $\sin a = \cos (l-d) - 2 \cos l \cos d \sin^2 \frac{1}{2}$ H. A.

$$\begin{aligned}
l &= 33°\ 30'\ \ 0''\ \text{N} \\
d &= \underline{13°\ 21'\ \ 6''\ \text{N}} \\
l-d &= 20°\ \ 8'\ 54''
\end{aligned}$$

Nat. cos $(l-d)=.93880$
Number $=.08355$
Nat. sin $a=.85525$
Whence $a=58°\ 47'\ 16''$

log $2=0.30103$
cos l $33°\ 30'=9.92111$
cos d $13°\ 21.1''=9.98810$
2 sin $\frac{1}{2}$ H. A. $13°\ 6.9''=8.71170$
log of number $=8.92194$
Number $=\ .08355$

Obs. Alt. ⊖ $=59°\ 24'\ 55''$
Cal. Alt. ⊖ $=58°\ 47'\ 16''$
Alt. Diff $=\ .37'\ 39''=37.7$ mi. *toward* observed body

Considering the azimuth and the altitude difference as the first course and distance run they are entered with the actual course and distance run between sights in a traverse; thus,

TRAVERSE

Course	Dist.	D. Lat. N	D. Lat. S	Dep. E	Dep. W
S 55° E	37.7	——	21.7	31.0	——
N N E	40	37.0	——	15.3	——

D. Lat. $=15.3'$ N   Dep. $=46.3'$ E
D. Long. $=55.5'$ E

Lat. D. R $=33°\ 30'$ N
D. Lat. $=\ 15.3'$ N
Lat. position $m=33°\ 45.3'$ N

Long. D. R. $=178°\ \ 0'$ E
D. Long. $=\ 55.5'$ E
Long. position $m=178°\ 55.5'$ E

The latitude and longitude of the position m, Fig. 4, is now used in computing the second altitude; thus,

Computation for Altitude at Second Sight

G. M. T., Apr. 25 $=15^h\ 41^m\ 13^s$
Long. (178° 55.5′ E) in time $=11^h\ 55^m\ 42^s$
L. M. T., Apr. 26 $=\ 3^h\ 36^m\ 55^s$
Eq. of T. $=+\ \ 2^m\ 12^s$
L. App. T., Apr. 26 $=\ 3^h\ 39^m\ \ 7^s$
$\frac{1}{2}$ H. A. $=27°\ 23'\ 22''$

Proceed exactly as with first sight and calculate the altitude by the same formula; thus,

$l=33°\ 45.3'$ N
$d=13°\ 25.5'$ N
$l-d=20°\ 19.8'$

Nat. cos $(l-d) = .93771$	$\log 2 = 0.30103$
Number $= .34237$	$\cos l$ 33° 45.3′ $= 9.91982$
Nat. sin $a = .59534$	$\cos d$ 13° 25.5′ $= 9.98797$
Whence $a = 36°\ 32'\ 13''$	2 sin ½ H. A. 27° 23.4′ $= 9.32568$
	log of number $= 9.53450$
	Number $= .34237$

Obs. Alt. $\ominus = 36°\ 53'\ 6''$
Cal. Alt. $\ominus = 36°\ 32'\ 13''$
Alt. Diff. $= 20'\ 53''$
Or = 20.9 mi. *toward* observed body

11. To find the true position x, Fig. 4, the distance $m\,x$ is first determined in the triangle $m\,t\,x$. The angle $m\,x\,t$ in

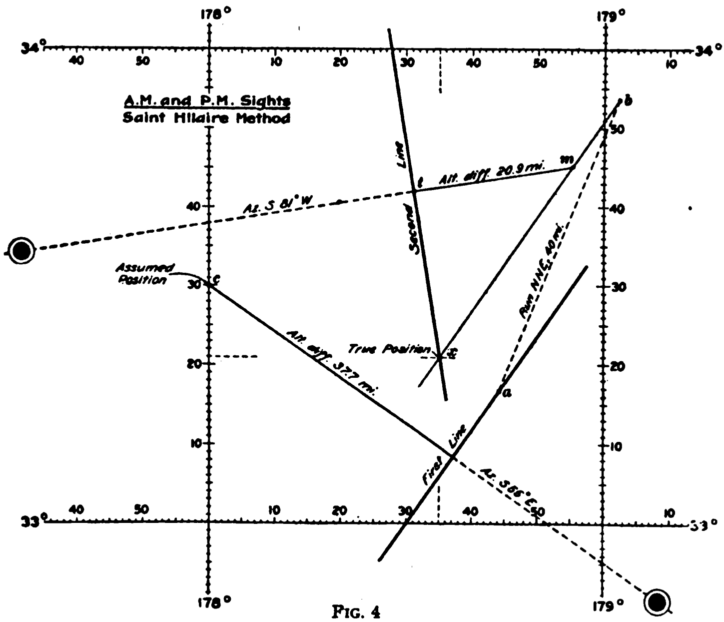


FIG. 4

this triangle is equal to the difference between the first and second lines of position. The first line runs in the direction N 35° E, the second line in the direction N 9° W; the angle $m\,x\,t$ is therefore $= 35° + 9° = 44°$. The triangle $m\,t\,x$ being a right triangle, the side $m\,x = t\,m \times \text{cosec}\ m\,x\,t$ or, $m\,x = 20.9 \times \text{cosec}\ 44°$.

$$\log 20.9 = 1.32015$$
$$\log \operatorname{cosec} 44^\circ = 0.15823$$
$$\log m\,x = 1.47838$$

whence, $\quad$ Dist. $m\,x = 30.09$ miles

Considering the direction of $m\,x$, S 35° W, as the course and its length, 30 miles, as the distance run, the corresponding difference of latitude and departure are, respectively, 24.6′ S and 17.2′ W, and the difference of longitude 20.6′ W. The true position x is then found by applying to position m these data. Thus,

Lat. m =	33° 45.3′ N	Long. m =	178° 55.5′ E
D. Lat. =	24.6′ S	D. Long. =	20.6′ W
Lat. x =	33° 20.7′ N	Long. x =	178° 34.9′ E

12. By examining the lines plotted in Fig. 4, it will be seen that the final fix x agrees with that obtained by Sumner's method. The first altitude difference, 37.7 miles, is laid off from the dead-reckoning position c toward the observed body along the line indicating the azimuth at the first sight. This establishes the first line of position at right angles to the azimuth. Then, after having found the latitude and longitude of the position m by means of the traverse, the second line of position is plotted in exactly the same way from that point along the azimuth line, as shown in the figure. The first line is then transferred as usual in the direction run between sights establishing the point of intersection x which is the true position of the ship.

13. The same data will now be used to calculate the two lines of position by the sine-cosine formula:

$$\sin a = \cos \text{H. A.} \cos d \cos l + \sin d \sin l$$

SECOND SOLUTION.—

Computation for Altitude at First Sight

G. M. T., Apr. 25 =	$10^h\ 20^m\ 56^s$
Long. (178° E) in time =	$11^h\ 52^m\ 0^s$
L. M. T., Apr. 25 =	$22^h\ 12^m\ 56^s$
Eq. of T. =	$+\ 2^m\ 9^s$
L. App. T., Apr. 25 =	$22^h\ 15^m\ 5^s$
H. A. =	$1^h\ 44^m\ 55^s$
Or =	26° 13′ 45″

cos H. A. 26° 13′ 45″ = 9.95281

sin l 33° 30′ = 9.74189	cos l = 9.92111
sin d 13° 21.1′ = 9.36347	cos d = 9.98810
log A = 9.10536	log B = 9.86202
A = .12746	B = .72781
	A = .12746
	Nat. sin $a = A + B$ = .85527
Obs. Alt. ⊖ = 59° 24′ 55″	Whence, a = 58° 47′ 24″
Cal. Alt. ⊖ = 58° 47′ 24″	

Alt. Diff. = 37′ 31″ = 37.5 mi. *toward* observed body

The latitude and longitude to be used in calculating the second altitude are found by applying to the assumed, or dead-reckoning, position the difference of latitude and the difference of longitude due to the run N N E, 40 mi. between the two sights.

Lat. D. R. = 33° 30′ N	Long. D. R. = 178° 0′ E
D. Lat. = 37′ N	D. Long. = 18.5′ E
Lat. in = 34° 7′ N	Long. in = 178° 18.5′ E

Computation for Altitude at Second Sight

G. M. T., Apr. 25 = $15^h\ 41^m\ 13^s$
Long. (178° 18.5′ E) in time = $11^h\ 53^m\ 14^s$
L. M. T., Apr. 26 = $3^h\ 34^m\ 27^s$
Eq. of T. + $2^m\ 12^s$
L. App. T., Apr. 26 = $3^h\ 36^m\ 39^s$
Or H. A. = 54° 9′ 45″

Cos H. A. 54° 9′ 45″ = 9.76752

sin l 34° 7′ = 9.74887	cos l = 9.91798
sin d 13° 25.5′ = 9.36581	cos d = 9.98797
log A = 9.11468	log B = 9.67347
A = .13022	B = .47149
	A = .13022
	Nat. sin $a = A + B$ = .60171
	Whence, a = 36° 59′ 32″

Obs. Alt. ⊖ = 36° 53′ 6″
Cal. Alt. ⊖ = 36° 59′ 32″
Alt. Diff. = 6′ 26″
Or = 6.4 mi. *from* observed body

The lines thus computed by the sine-cosine formula are plotted on the chart, Fig. 5, where c is the assumed position and a the second position from which the altitude differences are laid off. After the first line of position is plotted it is transferred as usual in the direction of the course and distance run, thus establishing the point x as the position of the ship at time of taking the second sight.

14. It will be noticed that the results attained by the two formulas agree in all particulars and in the final fix. The advantage, however, lies with the sine-cosine formula because of simplicity in computation and its adaptability to expeditious and accurate work. This formula compares most favorably with the other methods in the number of logarithms used and its chances of error, which are less than by any other method

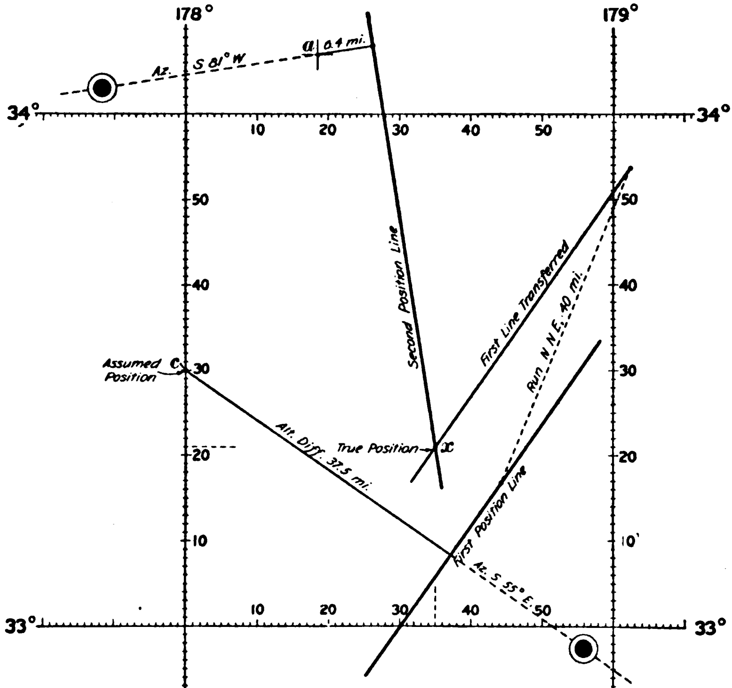


FIG. 5

of calculating the altitude. For these reasons the formula $\sin a = \sin l \sin d + \cos l \cos d \cos$ H. A. is selected for computing the altitude in the St. Hilaire method throughout this text.

15. Additional Formulas for Computing Altitude. Two other formulas for computing the altitude may be mentioned: The haversine and the cosine-haversine formulas. They call for special tables of haversines and each requires

about twice as many figures as the sine-cosine formula. The selection of formulas will always be a matter of personal preference with the individual navigator, but experience teaches that the simplest is the best.

16. Determining Position Lines by St. Hilaire's Method.—The general rule to be followed in using St. Hilaire's method of determining lines of position may be stated as follows:

Rule.—*Measure the altitude of the selected body and note the time by chronometer. Find the declination and equation of time corresponding to the G. M. T. With the longitude in by dead reckoning find the hour angle and reduce it to arc. Find also the azimuth of the observed body by tables, compass, or computation. Then with the latitude by dead reckoning, the declination, and the hour angle, calculate the true altitude by the formula given. Compare this altitude with the observed altitude reduced to true. The difference, expressed in miles, will be the distance from the dead-reckoning position where the line of position (Hilaire line) is located perpendicular to the line of azimuth.*

17. Altitude Difference of Observed Body.—If the observed altitude is greater than the calculated altitude, the altitude difference (Alt. Diff.) should be laid off toward the observed body; if less, it is laid off in the opposite direction.

It is then necessary to proceed in a like manner with the second observation and establish a second line of position which is plotted from the dead-reckoning position at time of measuring the second altitude.

If the ship has moved in the interval between sights, the first line of position is moved forwards parallel with itself, a distance equal to the course and distance run.

The intersection of the first line of position, transferred, with the second line will be the true position of the ship.

18. Accuracy and Value of St. Hilaire's Method.—To demonstrate the usefulness and accuracy of St. Hilaire's method, the illustrative examples that follow are worked out respectively with the Sumner and the St. Hilaire methods. This presents a clear and comprehensive way of estimating the comparative

value of the new method and its utilization under various conditions.

Example.—On August 14, 1914, at about 7.15 A. M., when the position by dead reckoning was estimated to be latitude 42° 15′ N and longitude 56° 30′ W an altitude of the sun's lower limb measured 22° 54′ 30″. After running N 60° E a distance of 32 miles, a second altitude of the sun's lower limb measured 48° 21′ 30″. The chronometer at first observation showed $11^h\ 2^m\ 26^s$ and at the second observation $1^h\ 23^m\ 53^s$, its error on Greenwich mean time being $1^m\ 27^s$ slow. Index error = −2′ 30″. Height of eye = 45 feet. The azimuth at first observation was N 102° E and at second observation, N 121° E. Find, by Sumner's (tangent) method and by St. Hilaire's method, the true position of the ship.

Solution by Sumner's Method.—

Computation for H. A. at First Sight

Chron. = $11^h\ 2^m\ 26^s$
Error (slow) = + $1^m\ 27^s$
G. M. T., Aug. 14 = $11^h\ 3^m\ 53^s$ A. M.

☉ Decl., Aug. 15 =	N 14° 15′ 0.2″	Change in 1^h =	46.52″
Corr. for $.95^h$ =	44.2″		×.95
☉ Corr. Decl. =	N 14° 15′ 44.4″	Corr. =	44.1940″
	90° 0′ 0″		
P. D. =	75° 44′ 16″		
Eq. of T., Aug. 15 =	$4^m\ 28.57^s$	Change in 1^h =	$.47^s$
Corr. for $.95^h$ = +	$.45^s$		×.95
Corr. Eq. of T. =	$4^m\ 29.02^s$ (+)	Corr. =	44.65^s

Obs. Alt. $\underline{\odot}$ =	22° 54′ 30″		
I. E. = −	2′ 30″		
	22° 52′ 0″		
Dip = −	6′ 36″		
	22° 45′ 24″		
S. D. = +	15′ 49″		
	23° 1′ 13″		
Par. Ref. = −	2′ 8″		
a =	22° 59′ 5″		
p =	75° 44′ 16″	cosec =	0.01359
l =	42° 15′ 0″	sec =	0.13064
	2)140° 58′ 21″		
S =	70° 29′ 10″	cos =	9.52379
$S-a$ =	47° 30′ 5″	sin =	9.86764
			2)19.53566
		log sin ½ H. A. =	9.76783

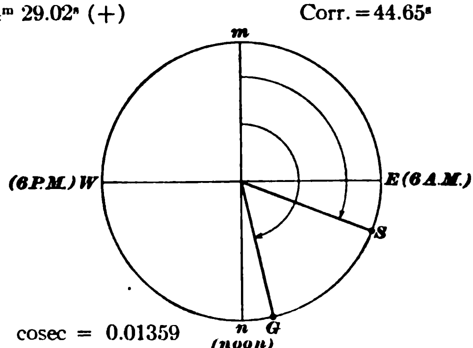


Fig. 6

L. App. T., Aug. 14 = $7^h\ 13^m\ 4^s$
Eq. of T. = $+\ 4^m\ 29^s$

Fig. 6 $\begin{cases} \text{L. M. T., Aug. 14} = 7^h\ 17^m\ 33^s \text{ A. M.} \\ \text{G. M. T., Aug. 14} = 11^h\ 3^m\ 53^s \text{ A. M.} \end{cases}$

Diff. = $3^h\ 46^m\ 20^s$
Long. = 56° 35′ W

Computation for H. A. at Second Sight

Chron. = $1^h\ 23^m\ 53^s$
Error (slow) = $+\ 1^m\ 27^s$
G. M. T., Aug. 15 = $1^h\ 25^m\ 20^s$ P. M.

⊙ Decl., Aug. 15 = N 14° 15′ 0.2″
Corr. for 1.4^h = − 1′ 5.1″
⊙ Corr. Decl. = N 14° 13′ 55.1″
= 90° 0′ 0″
P. D. = 75° 46′ 5″

Change in 1^h = 46.52″
×1.4
Corr. = 65.128
Or = 1′ 5.1″

Eq. of T., Aug. 15 = $4^m\ 28.57^s$
Corr. for 1.4^h = $-\ .66^s$
Eq. of T. = $4^m\ 27.91^s$ (+)

Change in 1^h = $.47^s$
×1.4
Corr. = $.658^s$

Obs. Alt. ☉ = 48° 21′ 30″
I. E. = − 2′ 30″
48° 19′ 0″
Dip = − 6′ 36″
48° 12′ 24″
S. D. = + 15′ 49″
48° 28′ 13″
Par. Ref. = − 45″
a = 48° 27′ 28″
p = 75° 46′ 5″ cosec = 0.01354
l = 42° 31′ 0″ sec = 0.13248
2)166° 44′ 33″
S = 83° 22′ 16″ cos = 9.06235
$S-a$ = 34° 54′ 48″ sin = 9.75765
2)18.96602
log sin ½ H. A. = 9.48301

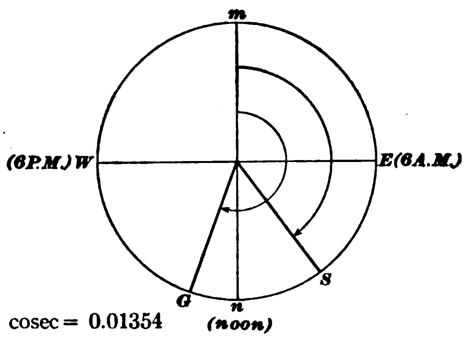


Fig. 7

L. App. T., Aug. 14 = $9^h\ 38^m\ 22^s$
Eq. of T. = $+\ 4^m\ 28^s$

Fig. 7 $\begin{cases} \text{L. M. T., Aug. 14} = 9^h\ 42^m\ 50^s \text{ A. M.} \\ \text{G. M. T., Aug. 14} = 13^h\ 25^m\ 20^s \text{ A. M.} \end{cases}$

Diff. = $3^h\ 42^m\ 30^s$
Long. = 55° 37.5′ W

Solution by St. Hilaire's Method.—To find the lines of position at each sight by the St. Hilaire method, the latitude and longitude by dead reckoning are used in combination with observed azimuths and the run made between sights, as follows:

Computation for Altitude at First Sight

G. M. T., Aug. 14 = $11^h\ 3^m\ 53^s$
Eq. of T. = $-\ 4^m\ 29^s$
G. App. T., Aug. 14 = $10^h\ 59^m\ 24^s$
Long. (56° 30′ W) in time = $3^h\ 46^m\ 0^s$
L. App. T., Aug. 14 = $7^h\ 13^m\ 24^s$ A. M.
Or, H. A. = $4^h\ 46^m\ 36^s$ from noon
In arc = 71° 39′

cos H. A. 71° 39′ = 9.49806
sin l 42° 15′ = 9.82761 cos l = 9.86936
sin d 14° 15′ 45″ = 9.39158 cos d = 9.98641
log A = 9.21919 log B = 9.35383
A = .16565 B = .22585
A = .16565
Nat. sin $a = A + B$ = .39150
Whence, a = 23° 2′ 53″

Obs. Alt. ⊖ = 22° 59′ 5″
Cal. Alt. ⊖ = 23° 2′ 53″
Alt. Diff. = 3′ 48″
Or = 3.8 mi. *from* observed body

Computation for Altitude at Second Sight

G. M. T., Aug. 15 = $13^h\ 25^m\ 20^s$ A. M.
Eq. of T. = $-\ 4^m\ 28^s$
G. App. T., Aug. 15 = $13^h\ 20^m\ 52^s$ A. M.
Long. (55° 53′ W) in time = $3^h\ 43^m\ 32^s$
L. App. T., Aug. 15 = $9^h\ 37^m\ 20^s$ A. M.
Or H. A. = $2^h\ 22^m\ 40^s$ = 35° 40′ from noon

cos H. A. 35° 40′ = 9.90978
sin l 42° 31′ = 9.82982 cos l = 9.86752
sin d 14° 14′ = 9.39071 cos d = 9.98646
log A = 9.22053 log B = 9.76376
A = .16616 B = .58044
A = .16616
Nat. sin $a = A + B$ = .74660
Whence, a = 48° 17′ 48″

Obs. Alt. ⊖ = 48° 27′ 28″
Cal. Alt. ⊖ = 48° 17′ 48″
Alt. Diff. = 9′ 40″
Or = 9.7 mi. *toward* observed body

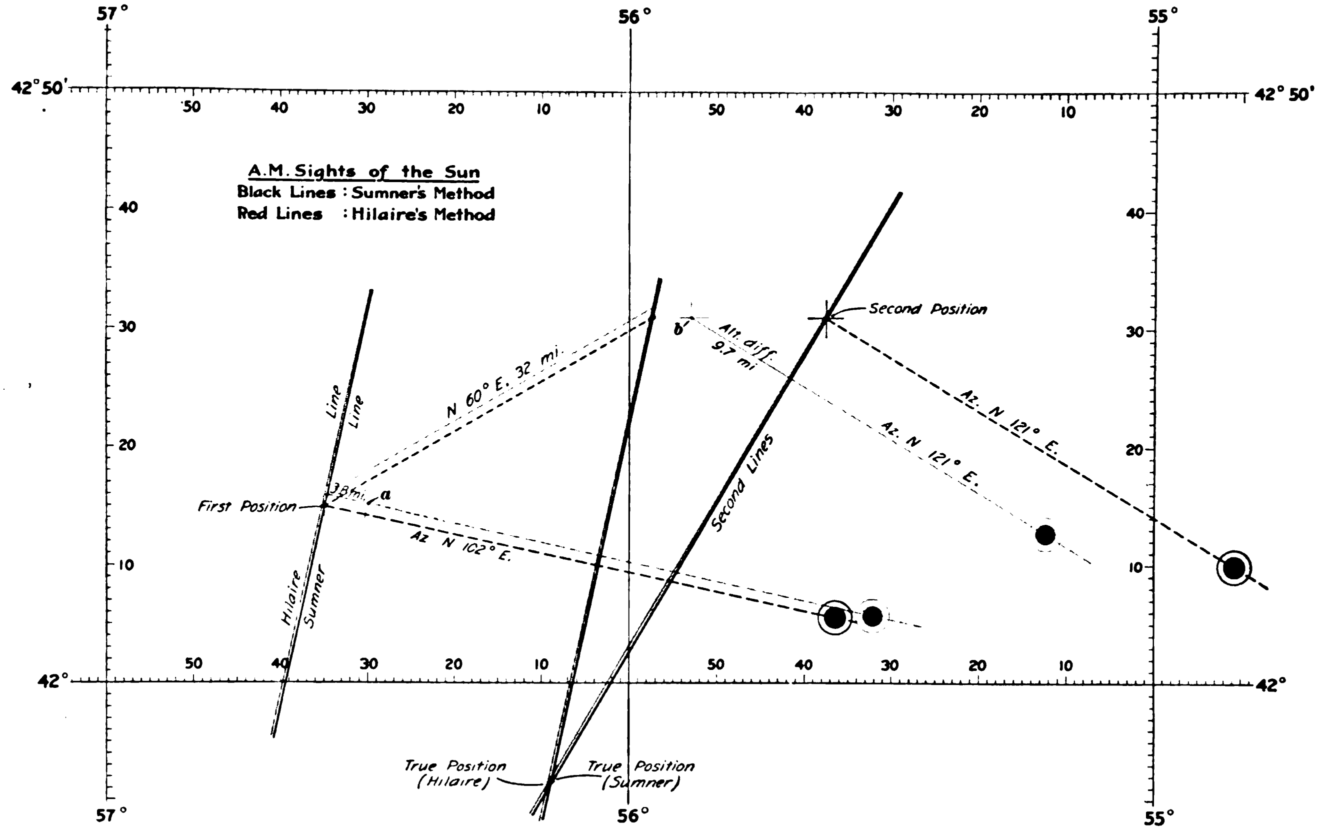

A.M. Sights of the Sun
Black Lines : Sumner's Method
Red Lines : Hilaire's Method
57°
56°
55°
42° 50'
42°
First Position
Second Position
True Position (Hilaire)
True Position (Sumner)
N 60° E. 32 mi.
Az N 102° E.
Az. N 121° E.
Alt. diff. 9.7 mi
3.8 mi.
a
b
Second Lines
Hilaire Line
Sumner Line

FIG. 8

§ 17 197B

19. The resulting lines of position are plotted on chart, Fig. 8. To distinguish between the different sets of lines those computed by Sumner's method are shown in black, while those by St. Hilaire's method are shown in red. The first position obtained by Sumner's method, latitude 42° 15′ N and longitude 56° 35′ W, is marked on the chart and the first line plotted at right angles to the azimuth N 102° E, as shown. The second Sumner line is plotted in like manner in latitude 42° 31′ N and longitude 55° 37.5′ W. The first line is then transferred parallel to itself according to course and distance run in the interval between observations. The intersection of this line with the second Sumner line will give the true position of the ship as latitude 41° 51.5′ N and longitude 56° 9′ W.

20. The first line of position by St. Hilaire's method is now plotted on the first line of azimuth from the dead-reckoning position, latitude 42° 15′ N and longitude 56° 30′ W, marked *a* on the chart. Since the observed altitude is less than the calculated altitude, the difference, 3.8 miles, is laid off from the observed body, as shown. The second azimuth is then plotted from the position *b*, which is obtained by allowing for run made from the dead-reckoning position. The difference in latitude and longitude corresponding to N 60° E, 32 miles, is found from the Traverse Tables and applied thus:

Lat. =	42° 15′ N	Long. =	56° 30′ W
D. Lat. =	16′ N	D. Long. =	37′ E
Lat. in =	42° 31′ N	Long. in =	55° 53′ W

21. The altitude difference in this case, 9.7 miles, is laid off toward the observed body since the observed altitude is greater than the calculated altitude. This brings the second line of position by St. Hilaire's method nearly in coincidence with the second Sumner line. The intersection of this line with the first line established by St. Hilaire's method, and brought forward parallel with itself, gives the true position of the ship within 1 mile of that found by Sumner's method.

22. Plotting Sheets.—The plotting of positions and lines should be made preferably on sheets known as Position Plotting

Sheets*. These sheets are constructed on the Mercator's projection and cover, in ten separate sheets, the latitudes from the equator to 53° N and S. Since the distance between meridians on these sheets is not less than 4 inches, they are more convenient and accurate for use in plotting positions than the ordinary sailing charts. The navigating outfit of every deep-sea going vessel should therefore include at least three or four sets of such plotting sheets. When the true position of a fix has been plotted on such a sheet, it is transferred to the regular chart which is thus saved from much wear and tear.

23. In the problem that follows both sights are taken in the afternoon. Both solutions should be carefully noted.

EXAMPLE.—On September 17, 1914, in the afternoon, the measured altitude of the sun's lower limb was 52° 4′, the corresponding Greenwich mean time being $16^h\ 17^m\ 20^s$. After a run S 50° W, 54 miles, a second sight was taken at which the altitude of the sun's lower limb was 16° 28′ 30″, the Greenwich mean time being $19^h\ 35^m\ 28^s$. The chronometer was $1^m\ 40^s$ slow on Greenwich mean time. Index error = −2′ 30″. Height of eye = 32 feet. The true azimuth at first sight was S 40° W; at second sight, S 82° W. The position of the ship was very uncertain but was estimated to be latitude 33° 53′ N, and longitude 137° 3′ E. Find, by Sumner's method, and also by St. Hilaire's method, the true position of the ship.

SOLUTION BY SUMNER'S METHOD.—

Computation for H. A. at First Sight

Chron. =	$16^h\ 17^m\ 20^s$
Error (slow) =	$+\ \ 1^m\ 40^s$
G. M. T., Sept. 16 =	$16^h\ 19^m\ 0^s$

⊙Decl., Sept. 17 =	N 2° 29′ 12.2″	Change in 1^h =	58.0″
Corr. for 7.7^h =	+ 7′ 26.6″		×7.7
⊙Corr. Decl. =	N 2° 36′ 38.8″	Corr. =	446.6″
	90° 0′ 0″	Or =	7′ 26.6″
P. D. =	87° 23′ 21″		
Eq. of T., Sept. 17 =	$5^m\ 17.06^s$	Change in 1^h =	$.882^s$
Corr. for 7.7^h =	$-\ 6.79^s$		×7.7
Corr. Eq. of T. =	$5^m\ 10.27^s(-)$	Corr. =	6.7914^s

* Plotting Sheets are published and sold by the United States Hydrographic Office at 10 cents a sheet.

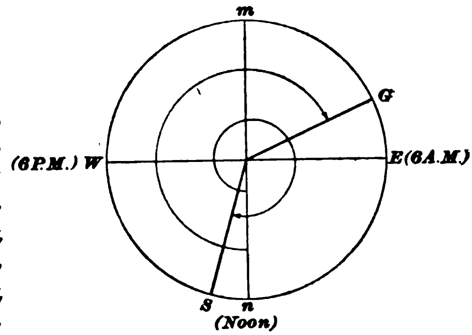


FIG. 9

Obs. Alt. $\underline{\odot}$ =	52° 4′ 0″		
I. E. =	− 2′ 30″		
	52° 1′ 30″		
Dip =	− 5′ 32″		
	51° 55′ 58″		
$\odot$ S. D. =	+ 15′ 57″		
	52° 11′ 55″		
Par. Ref. =	− 39″		
a =	52° 11′ 16″		
p =	87° 23′ 21″	cosec =	0.00045
l =	33° 53′ 0″	sec =	0.08083
	2)173° 27′ 37″		
S =	86° 43′ 48″	cos =	8.75619
$S-a$ =	34° 32′ 32″	sin =	9.75360
			2) 18.59107

log sin $\frac{1}{2}$ H. A. = 9.29553
L. App. T., Sept. 17 = $1^h\ 31^m\ 7^s$ P. M.
Eq. of T. = − $5^m\ 10^s$

See Fig. 9 {
L. M. T., Sept. 17 = $1^h\ 25^m\ 57^s$ P. M.
Or, Sept. 16 = $25^h\ 25^m\ 57^s$ P. M.
G. M. T., Sept. 16 = $16^h\ 19^m\ 0^s$ P. M.

Diff. = $9^h\ 6^m\ 57^s$
Long. = 136° 44′ 15″ E

Computation for H. A. at Second Sight

Chron. = $19^h\ 35^m\ 28^s$
Error (slow) = + $1^m\ 40^s$
G. M. T., Sept. 16 = $19^h\ 37^m\ 8^s$

$\odot$ Decl., Sept. 17 = N	2° 29′ 12.2″	Change in 1^h =	58.0″
Corr. for 4.4^h =	4′ 15.2″		×4.4
$\odot$ Corr. Decl. = N	2° 33′ 27.4″	Corr. =	255.2″
	90° 0′ 0″	Or =	4′ 15.2″
P. D. =	87° 26′ 33″		

Eq. of T., Sept. 17 =	$5^m\ 17.06^s$	Change in 1^h =	$.882^s$
Corr. for 4.4^h =	− 3.88		×4.4
Corr. Eq. of T. =	$5^m\ 13.18^s$ (−)	Corr. =	3.8808^s

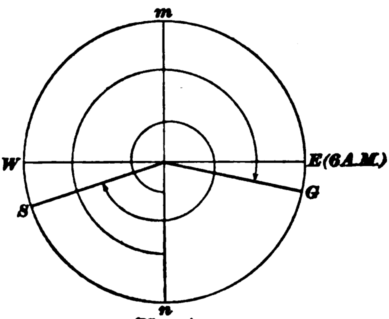


Fig. 10

Obs. Alt. ☉ =	16° 28′ 30″		
I. E. =	− 2′ 30″		
	16° 26′ 0″		
Dip =	− 5′ 32″		
	16° 20′ 28″		
S. D. =	+ 15′ 57″		
	16° 36′ 25″		
Par. Ref. =	− 3′ 4″		
a =	16° 33′ 21″		
p =	87° 26′ 33″	cosec =	0.00043
l =	33° 18′ 18″	sec =	0.07792
	2)137° 18′ 12″		
S =	68° 39′ 6″	cos =	9.56115
$S-a$ =	52° 5′ 45″	sin =	9.89709
			2)19.53659

log sin ½ H. A. =	9.76829
L. App. T., Sept. 17 =	$4^h\ 47^m\ 17^s$
Eq. of T. =	$-\ 5^m\ 13^s$
See Fig. 10 { L. M. T., Sept. 17 =	$4^h\ 42^m\ 4^s$
Or, Sept. 16 =	$28^h\ 42^m\ 4^s$
G. M. T., Sept. 16 =	$19^h\ 37^m\ 8^s$
Diff. =	$9^h\ 4^m\ 56^s$
Long. =	136° 14′ E

Solution by St. Hilaire's Method.—When working out the first position line, the latitude and longitude of the assumed position of the ship are used. For the second line, the same latitude and longitude are used after both have been corrected for the run made by the ship in the interval between sights.

Computation for Altitude at First Sight

G. M. T., Sept. 16 =	$16^h\ 19^m\ 0^s$
Eq. of T. =	$+\ 5^m\ 10^s$
G. App. T., Sept. 16 =	$16^h\ 24^m\ 10^s$
Long. 137° 3′ E in time =	$9^h\ 8^m\ 12^s$
L. App. T., Sept. 16 =	$25^h\ 32^m\ 22^s$
Or, Sept. 17 =	$1^h\ 32^m\ 22^s$
Whence, H. A. =	23° 5′ 30″

$$\begin{array}{rr}
 & \cos \text{H. A. } 23° \, 5' \, 30'' = 9.96373 \\
\sin l \; 33° \, 53' = 9.74625 & \cos l = 9.91917 \\
\sin d \; 2° \, 36' \, 39'' = \underline{8.65850} & \cos d = \underline{9.99955} \\
\log A = 8.40475 & \log B = 9.88245 \\
A = .02540 & B = .76287 \\
 & A = \underline{.02540} \\
 & \text{Nat. } \sin a = A + B = .78827 \\
 & \text{Whence } a = 52° \, 1' \, 27''
\end{array}$$

$$\begin{array}{lr}
\text{Obs. Alt. } \ominus & = 52° \, 11' \, 16'' \\
\text{Cal. Alt. } \ominus & = \underline{52° \;\; 1' \, 27''} \\
\text{Alt. Diff.} = & 9' \, 49''
\end{array}$$

Or = 9.8 mi. *toward* observed body

24. The altitude at the second sight is now calculated by using the assumed latitude and longitude corrected for run between sights which is obtained as follows: Entering the Traverse Tables with course S 50° W and the distance 54 miles, the corresponding difference of latitude and departure are, respectively, 34.7′ S and 41.4′ W. The difference of longitude corresponding to a departure of 41.4 and a middle latitude of 33° 30′ is 49.7′ W.

$$\begin{array}{lrr}
\text{Hence,} & \text{Lat.} = 33° \, 53' \;\; \text{N} & \text{Long.} = 137° \, 3' \;\;\; \text{E} \\
 & \text{D. Lat.} = \underline{34.7' \; \text{S}} & \text{D. Long.} = \underline{49.7' \; \text{W}} \\
 & \text{Lat. in} = 33° \, 18.3' \; \text{N} & \text{Long. in} = 136° \, 13.3' \; \text{E}
\end{array}$$

Computation for Altitude at Second Sight

$$\begin{array}{rr}
\text{G. M. T., Sept. } 16 = & 19^h \, 37^m \;\; 8^s \\
\text{Eq. of T.} = & \underline{+ \;\;\; 5^m \, 13^s} \\
\text{G. App. T., Sept. } 16 = & 19^h \, 42^m \, 21^s \\
\text{Long. } (136° \, 13' \, 18'' \text{ E}) \text{ in time} = & \underline{9^h \;\; 4^m \, 53^s} \\
\text{L. App. T., Sept. } 16 = & 28^h \, 47^m \, 14^s \\
\text{Or, Sept. } 17 = & 4^h \, 47^m \, 14^s \text{ P. M.} \\
\text{Whence, H. A.} = & 71° \, 48' \, 30''
\end{array}$$

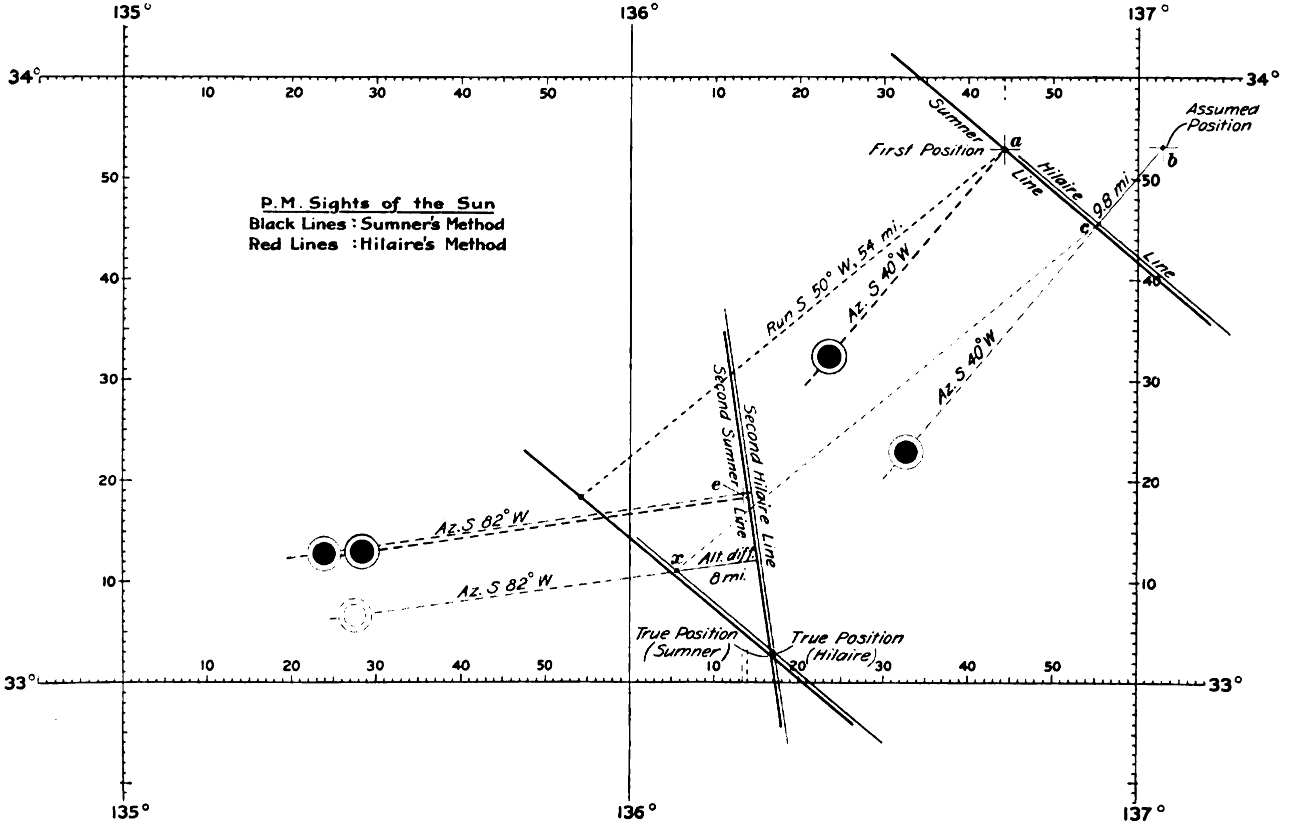
$$\begin{array}{rr}
 & \cos \text{H. A. } 71° \, 48' \, 30'' = 9.49443 \\
\sin l \; 33° \, 18' \, 18'' = 9.73965 & \cos l = 9.92208 \\
\sin d \; 2° \, 33' \, 27'' = \underline{8.64954} & \cos d = \underline{9.99956} \\
\log A = 8.38919 & \log B = 9.41607 \\
A = .02450 & B = .26066 \\
 & A = \underline{.02450} \\
 & \text{Nat. } \sin a = A + B = .28516 \\
 & \text{Whence, } a = 16° \, 34' \, 6''
\end{array}$$

Obs. Alt. ⊖ = 16° 33′ 21″
Cal. Alt. ⊖ = 16° 34′ 6″
Alt. Diff. = 45″
Or = .8 mi. *from* observed body

NOTE.—In determining the numbers corresponding to log A and log B the student must keep in mind the fact that −10 is understood to follow the values of log A and log B. Thus, log $A = 8.38919 - 10$, or $\bar{2}.38919$, and log $B = 9.41607 - 10$, or $\bar{1}.41607$. The student must remember this in order to avoid confusion regarding the position of the decimal point in A and B.

25. The first line of position by Sumner's method is now plotted on the chart, a representation of which is shown in Fig. 11. The sun's true azimuth S 40° W at first sight is projected from the point *a* in latitude 33° 53′ N and longitude 136° 44′ 15″ E, which is the first position obtained by Sumner's method. A line drawn perpendicular to the azimuth will be the first Sumner line. In the same manner the second Sumner line is plotted in latitude 33° 18.3′ N and longitude 136° 14′ E, which is the second position obtained by Sumner's method. Then the first line is transferred parallel with itself in the direction of the run made between sights, S 50° W, 54 miles. The intersection of this line with the second Sumner line will give the true position of the ship by Sumner's method at the time the second observation was made.

26. To plot the lines calculated by St. Hilaire's method, the assumed, or dead-reckoning, position is used as a base. From this point *b* in latitude 33° 53′ N and longitude 137° 3′ E the first azimuth S 40° W is laid off as shown in Fig. **11**. Since the observed altitude in this case is greater than the calculated altitude, the difference between the altitudes, 10 miles (also known as *intercept*) is laid off toward the observed body, and through the point *c* thus established, and perpendicular to the azimuth, is drawn the first line of position found by St. Hilaire's method. For the sake of convenience, this line may be named the first Hilaire line to distinguish it from the Sumner line. The second line of position by St. Hilaire's method is plotted in a like manner from the position *e* which is found by applying to the assumed position the difference of latitude and the difference of longitude due to the run between sights, as already shown in calculation for altitude at second sight. From this



P.M. Sights of the Sun
Black Lines : Sumner's Method
Red Lines : Hilaire's Method
135°
136°
137°
34°
33°
Assumed Position
First Position
Sumner Line
Hilaire Line
9.8 mi.
Run S 50° W. 54 mi.
Az. S 40° W
Az. S 40° W
Second Sumner Line
Second Hilaire Line
Az. S 82° W
Az. S 82° W
Alt. diff. 8 mi.
True Position (Sumner)
True Position (Hilaire)

Fig. 11

point *e*, along the azimuth line S 82° W, but in opposite direction, or away from the observed body, is laid off the altitude difference of 1 mile, since in this case the observed altitude is less than the calculated altitude.

27. The first Hilaire line is now transferred parallel with itself, a distance and in a direction equal to the course and distance run, and its point of intersection with the second Hilaire line will give the true position of the ship. It will be noticed that the true positions obtained, respectively, by Sumner's and St. Hilaire's methods differ slightly in longitude. This difference is due to logarithms and to the plotting of lines made purposely to separate the two sets of lines. By more rigorous computation and plotting, the lines of position by both methods will coincide.

28. Locating Second Plotting Point.—Advocates of the St. Hilaire method in some cases suggest the use of the first

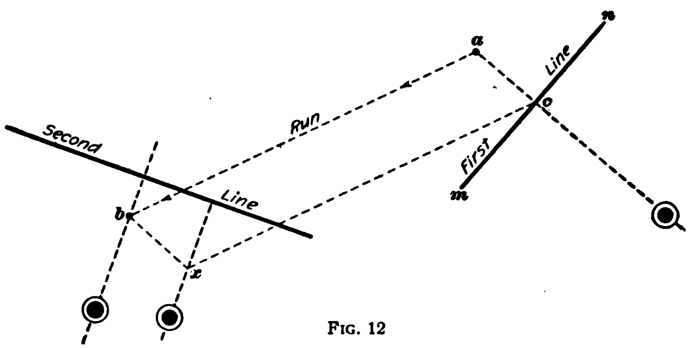


FIG. 12

point of position for use as a base in the calculation of the second altitude as a substitute for the assumed latitude and longitude corrected for run between sights. Thus, if *a*, Fig. 12, is the assumed, or dead-reckoning, position when the first observation is made, *a c* the altitude difference, and *c* the first position point on the line *m n*, it is proposed to use *c* as the point from which to locate the second plotting point *x*, assuming *a b* to be the run between observations. In other words, instead of using the latitude and longitude of *a*, corrected for the run

made between sights as $a\,b$, it is suggested to use $a\,c$, in this case the reverse of bearing, as first course and the run as second course, $c\,x$ ($=a\,b$), to obtain the point x from which to plot the second bearing of the observed body. Provided no errors are made, it is immaterial which procedure is used. The resulting lines of position will come out alike, whether the latitude and longitude of the point x, or of the point b is used in calculating the altitude for the second sight.

29. The advantage is in favor of using b, which is obtained directly by applying to a the difference of latitude and the difference of longitude due to the run $a\,b$.

To demonstrate the similarity in the position of lines resulting from using the different points referred to, the latitude and longitude of the point x on chart, Fig. 11, will be used in calculating the second altitude. This point x is obtained by applying to the assumed, or dead-reckoning, position, the distances due to the altitude difference and the run made between sights. Thus from the assumed position, latitude 33° 53′ N and longitude 137° 3′ E, the azimuth and the altitude difference, 10 miles, are considered the first course and distance run while the actual run S 50° W, 54 miles, is considered the second course and distance run. These are entered in a traverse as follows:

TRAVERSE

Courses	Dist.	D. Lat.		Dep.	
		N	S	E	W
S 40° W	9.8	——	7.5	——	6.3
S 50° W	54.0	——	34.7	——	41.4

D. Lat. = 42.2′ S Dep. = 47.7′ W
D. Long. = 57.2′ W

and applied to the assumed latitude and longitude in the usual way, thus

Lat. b = 33° 53′ N	Long. b = 137° 3′ E
D. Lat. = 42.2′ S	D. Long. = 57.2′ W
Lat. x = 33° 10.8′ N	Long. x = 136° 5.8′ E

30. The same values of latitude and longitude are again used in calculating the second altitude, thus:

$$
\begin{array}{rl}
\text{G. M. T., Sept. } 16 = & 19^h\ 37^m\ \ 8^s \\
\text{Eq. of T.} = & +\ \ \ \ 5^m\ 13^s \\
\hline
\text{G. App. T., Sept. } 16 = & 19^h\ 42^m\ 21^s \\
\text{Long. } (136°\ 5'\ 48''\text{ E) in time} = & \ \ 9^h\ \ 4^m\ 23^s \\
\hline
\text{L. App. T., Sept. } 16 = & 28^h\ 46^m\ 44^s \\
\text{Or, Sept. } 17 = & \ \ 4^h\ 46^m\ 44^s\text{ P. M.} \\
\text{Whence, H. A.} = & 71°\ 41'
\end{array}
$$

$$
\begin{array}{rlrl}
 & & \cos\text{ H. A. } 71°\ 41' = & 9.49730 \\
\sin l\ 33°\ 10'\ 36'' = & 9.73816 & \cos l = & 9.92272 \\
\sin d\ \ 2°\ 33'\ 27'' = & 8.64954 & \cos d = & 9.99956 \\
\hline
\log A = & 8.38770 & \log B = & 9.41958 \\
A = & .02442 & B = & .26277 \\
 & & A = & .02442 \\
\hline
 & & \text{Nat. } \sin a = A + B = & .28719 \\
 & & \text{Whence, } a = & 16°\ 41'\ 24''
\end{array}
$$

$$
\begin{array}{rl}
\text{Obs. Alt. } \ominus = & 16°\ 33'\ 21'' \\
\text{Cal. Alt. } \ominus = & 16°\ 41'\ 24'' \\
\hline
\text{Alt. Diff.} = & \ \ \ \ \ \ 8'\ \ 3'' \\
 & \text{Or} = 8\text{ mi. } \textit{from}\text{ observed body}
\end{array}
$$

31. The altitude difference thus obtained, 8 miles, when laid off from x (see chart Fig. 11) along the direction of the second azimuth, away from the sun, places the resulting line of position in almost exact coincidence with the line previously obtained, showing identical results arrived at by the two methods employed in calculating the second Hilaire line.

32. Navigators who use the position point fixed by the first line in preference to the original assumed, or dead-reckoning, position should make sure to use the latitude and longitude of that point and not that of the dead-reckoning position when calculating the second altitude.

33. Two forenoon sights, each worked out by Sumner's and St. Hilaire's methods, are given in the following illustration. In this problem the run between sights is considerable.

EXAMPLE.—On July 6, 1914, at 6:15 A. M., in latitude 47° 48′ N and longitude 33° 45′ W, by dead reckoning, the altitude of the sun's lower limb measured 19° 0′ 30″. The chronometer at instant of sight was $8^h\ 56^m\ 59^s$, its error on Greenwich mean time being $23^m\ 46^s$ fast. Height

of eye = 36 feet. No index error. The azimuth at time of sight was N 76° 30′ E. After a run N 75° E, 83 miles, a second sight of the sun's lower limb was taken, the altitude being 61° 2′ 30″ and the chronometer $1^h\ 27^m\ 21^s$. The azimuth at this sight was S 34° E. Find, by Sumner's and St. Hilaire's methods, the true position of the ship at second observation.

SOLUTION BY SUMNER'S METHOD.—

Computation for H. A. at First Sight

Chron. $= 8^h\ 56^m\ 59^s$
Error (fast) $= -\ 23^m\ 46^s$
G. M. T., July 6 $= 8^h\ 33^m\ 13^s$ A. M.

⊙ Decl., July 6 = N 22° 45′ 44″ — Change in 1^h = 14.45″
Corr. = + 49″ — ×3.4
⊙ Corr. Decl. = N 22° 46′ 33″ — Corr. = 49.130″
90° 0′ 0″
P. D. = 67° 13′ 27″

Eq. of T., July 6 $= 4^m\ 23.54^s$ — Change in 1^h = $.425^s$
Corr. $= -\ 1.44^s$ — ×3.4
Corr. Eq. of T. $= 4^m\ 22.10^s$ (+) — Corr. $= 1.4450^s$

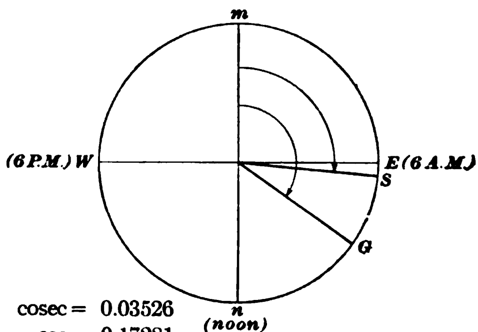


FIG. 13

Obs. Alt. $\underline{\odot}$ = 19° 0′ 30″
Dip = − 5′ 53″
18° 54′ 37″
S. D. = + 15′ 46″
19° 10′ 23″
Par. Ref. = − 2′ 37″
a = 19° 7′ 46″
p = 67° 13′ 27″ cosec = 0.03526
l = 47° 48′ 0″ sec = 0.17281
2)134° 9′ 13″
S = 67° 4′ 36″ cos = 9.59051
$S-a$ = 47° 56′ 50″ sin = 9.87071
2)19.66929
log sin ½ H. A. = 9.83464
L. App. T., July 6 $= 6^h\ 15^m\ 9^s$ A. M.
Eq. of T. $= +\ 4^m\ 22^s$

Fig. 13 { L. M. T., July 6 $= 6^h\ 19^m\ 31^s$ A. M.
G. M. T., July 6 $= 8^h\ 33^m\ 13^s$ A. M.

Diff. $= 2^h\ 13^m\ 42^s$
Long. = 33° 25′ 30″ W

Computation for H. A. at Second Sight

Chron. = $1^h\ 27^m\ 21^s$
Error (fast) = $-\ 23^m\ 46^s$
G. M. T., July 6 = $1^h\ 3^m\ 35^s$

☉ Decl., July 6 = N 22° 45′ 44″ Change in 1^h = 14.45″
Corr. = − 16″ ×1.1
☉ Corr. Decl. = N 22° 45′ 28″ Corr. = 15.895″
90° 0′ 0″
P. D. = 67° 14′ 32″

Eq. of T., July 6 = $4^m\ 23.54^s$ Change in 1^h = $.425^s$
Corr. = + $.46^s$ ×1.1
Corr. Eq. of T. = $4^m\ 24^s$ (+) Corr. = $.4675^s$

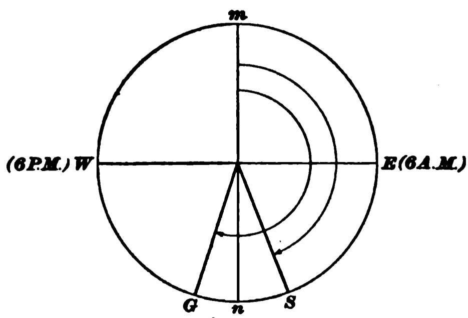


Fig. 14

Obs. Alt. ☉ = 61° 2′ 30″
Dip = − 5′ 53″
60° 56′ 37″
S. D. = + 15′ 46″
61° 12′ 23″
Par. Ref. = − 28″
a = 61° 11′ 55″
p = 67° 14′ 32″ cosec = 0.03520
l = 48° 9′ 30″ sec = 0.17583
2)176° 35′ 57″
S = 88° 17′ 58″ cos = 8.47240
$S-a$ = 27° 6′ 3″ sin = 9.65854
2)18.34197
log sin ½ H. A. = 9.17099
L. App. T., July 6 = $10^h\ 51^m\ 48^s$
Eq. of T. = + $4^m\ 24^s$
Fig. 14 { L. M. T., July 6 = $10^h\ 56^m\ 12^s$ A. M.
G. M. T., July 6 = $13^h\ 3^m\ 35^s$ A. M.
Diff. = $2^h\ 7^m\ 23^s$
Long. = 31° 50′ 45″ W

SOLUTION BY ST. HILAIRE'S METHOD.—Use the latitude and longitude of the assumed, or dead-reckoning, position and calculate altitude for first sight. Then calculate the altitude for the second sight, using the same

assumed latitude and longitude corrected for run made between sights. Thus:

Computation for Altitude at First Sight

G. M. T., July 6 = $8^h\ 33^m\ 13^s$ A. M.
Eq. of T. = $-\ 4^m\ 22^s$
G. App. T., July 6 = $8^h\ 28^m\ 51^s$
Long. (33° 45′ W) in time = $2^h\ 15^m\ 0^s$
L. App. T., July 6 = $6^h\ 13^m\ 51^s$
Or, H. A. = $5^h\ 46^m\ 9^s$
In arc = 86° 32′ 15″

cos H. A. 86° 32′ 15″ = 8.78100
sin l 47° 48′ = 9.86970 cos l = 9.82719
sin d 22° 46′ 33″ = 9.58786 cos d = 9.96474
log A = 9.45756 log B = 8.57293
A = .28679 B = .03741
A = .28679
Nat. sin $a = A + B$ = .32420
Whence a = 18° 55′ 2″

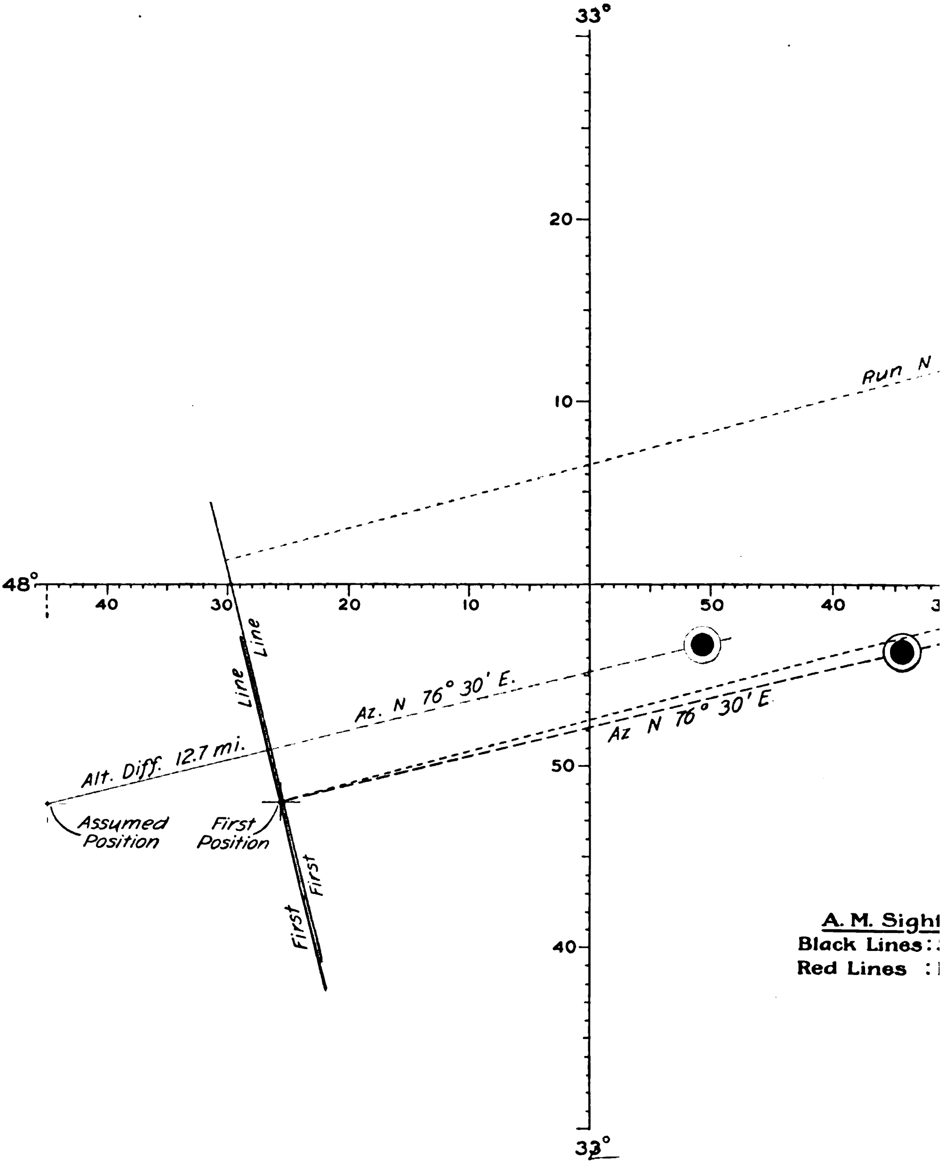
Obs. Alt. ⊖ = 19° 7′ 46″
Cal. Alt. ⊖ = 18° 55′ 2″
Alt. Diff. = 12′ 44″
Or = 12.7^m *toward* observed body

Computation for Altitude at Second Sight

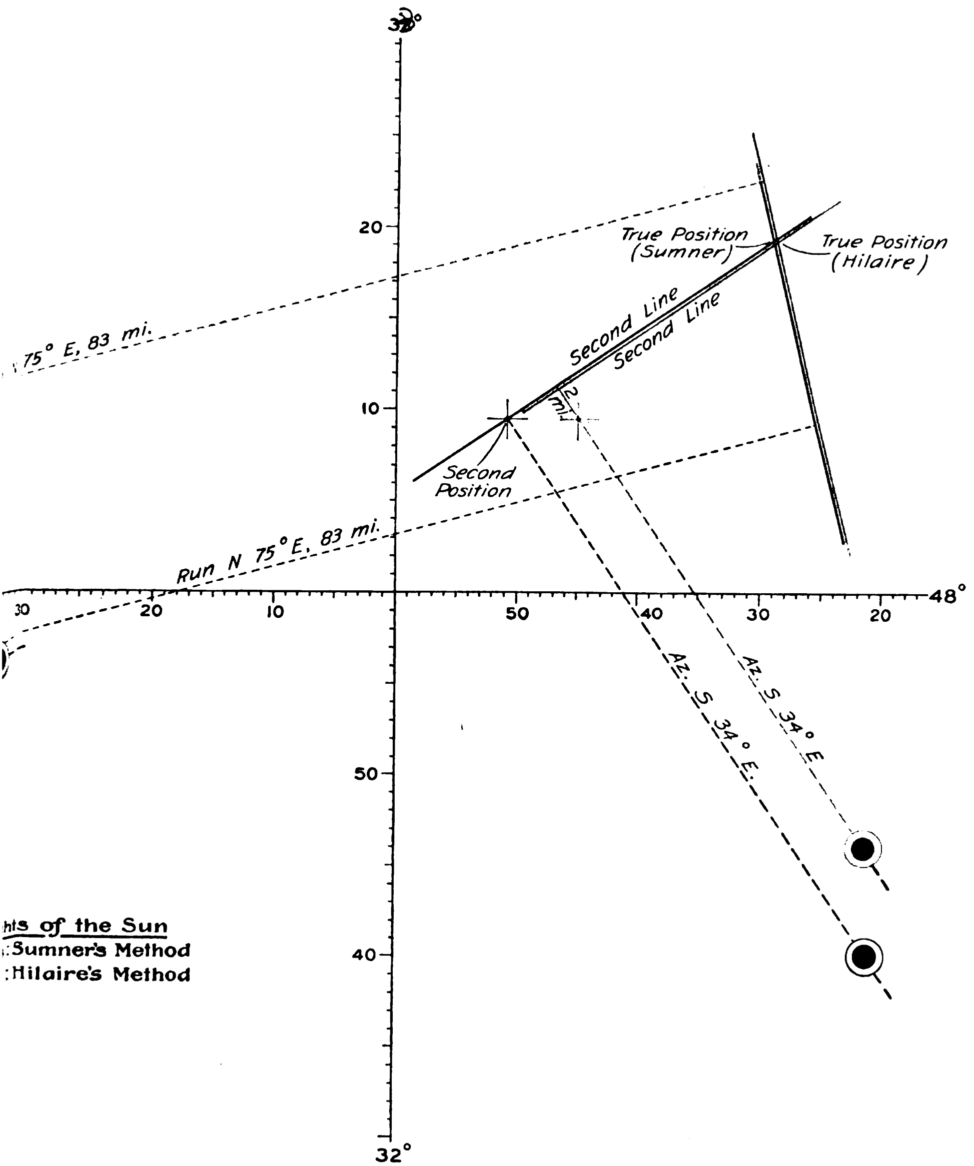
G. M. T., July 6 = $13^h\ 3^m\ 35^s$ A. M.
Eq. of T. = $-\ 4^m\ 24^s$
G. App. T., July 6 = $12^h\ 59^m\ 11^s$
Long. (31° 45′ W) in time = $2^h\ 7^m\ 0^s$
L. App. T., July 6 = $10^h\ 52^m\ 11^s$ A. M.
Or, H. A. = $1^h\ 7^m\ 49^s$ = 16° 57′ 15″

cos H. A. 16° 57′ 15″ = 9.98070
sin l 48° 9′ 30″ = 9.87215 cos l = 9.82417
sin d 22° 45′ 28″ = 9.58753 cos d = 9.96480
log A = 9.45968 log B = 9.76967
A = .28819 B = .58840
A = .28819
Nat. sin $a = A + B$ = .87659
Whence a = 61° 14′

Obs. Alt. ⊖ = 61° 11′ 55″
Cal. Alt. ⊖ = 61° 14′ 0″
Alt. Diff. = 2′ 5″
Or = 2.1 mi. *from* observed body


33°
20
10
50
40
33°
48°
40
30
20
10
50
40
Run N
Line
Line
Az. N 76° 30' E.
Alt. Diff. 12.7 mi.
Assumed Position
First Position
First
First
Az N 76° 30' E
A. M. Sigh
Black Lines
Red Lines

FIG



hts of the Sun
:Sumner's Method
:Hilaire's Method

IG. 15

34. Position of Lines by Each Method.—The two sets of lines derived, respectively, by Sumner's and St. Hilaire's methods, are plotted on chart, Fig. 15. The lines of position by each method agree very closely and the resulting true positions are separated by less than ½ mile. If the two calculations had been worked out more rigorously, the lines and final fix would coincide.

In the last two examples the latitude and longitude by dead reckoning were greatly in error, yet the final fix was determined within 1 mile of the actual position of the ship by the Hilaire method, in one case by P. M. and in the other case by A. M. sights.

35. In order to attain proficiency, it is suggested that all solutions to examples appearing throughout the text be worked out independently instead of merely glancing over the solutions. The printed solutions may then be used as a guide to discover where mistakes were made in case of unlike results.

EXAMPLE 1.—About 7 o'clock in the morning of October 11, 1914, the observed altitude of the sun's lower limb was found to be 13° 45′ 40″. Index error = −1′ 40″. Height of eye = 45 feet. At the instant of observation, the time shown by the chronometer was $11^h\ 56^m\ 15^s$, its error on Greenwich mean time being $1^m\ 48^s$ fast. By dead reckoning, the latitude and longitude were 41° 41′ N and 66° 28′ W, respectively. About 10 o'clock in the morning of the same day, the observed altitude of the sun's lower limb was 38° 43′ 10″. The chronometer time at that instant was $3^h\ 3^m\ 39^s$, its error being the same as at the first observation. Run between sights was S 58½° W, 51 miles. Find the ship's true position at the time of the second observation by the use of both the Sumner and the St. Hilaire methods.

SOLUTION BY SUMNER'S METHOD.—

Computation for H. A. and Az. at First Sight

Approx. L. M. T., Oct. 11 = $7^h\ 0^m\ 0^s$ A. M.
Long. W. in time = $4^h\ 25^m\ 52^s$
Approx. G. M. T., Oct. 11 = $11^h\ 25^m\ 52^s$ A. M.
Or, Oct. 10 = $23^h\ 25^m\ 52^s$

Chron. = $11^h\ 56^m\ 15^s$
Error (fast) = − $1^m\ 48^s$
G. M. T., Oct. 11 = $11^h\ 54^m\ 27^s$ A. M.
Or, Oct. 10 = $23^h\ 54^m\ 27^s$

☉ Decl., Oct. 11 = S 6° 48′ 22″ Change in 1^h = 57″
Corr. for $.1^h$ = − 6″ .1
Corr. Decl. = S 6° 48′ 16″ Corr. = 5.7″
P. D. = 96° 48′ 16″
Corr. Eq. of T. = 13^m 3^s (−) Corr. = .651 × .1 = .0651^s

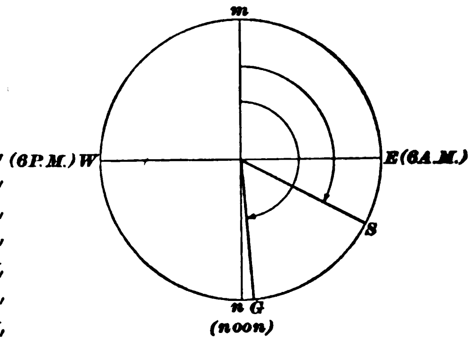


Fig. 16

Obs. Alt. ☊ = 13° 45′ 40″
I. E. = − 1′ 40″
13° 44′ 0″
Dip. = − 6′ 36″
App. Alt. ☊ = 13° 37′ 24″
S. D. = + 16′ 3″
13° 53′ 27″
Par. Ref. = − 3′ 43″

a =	13° 49′ 44″		sec =	.01277
p =	96° 48′ 16″	cosec = .00307		
l =	41° 41′ 0″	sec = .12678	sec =	.12678
	2)152° 19′ 0″			
S =	76° 9′ 30″	cos = 9.37884	cos =	9.37884
$S-a$ =	62° 19′ 46″	sin = 9.94725		
$p-S$ =	20° 38′ 46″		cos =	9.97117
		2)19.45594		2)19.48956

log sin ½ H. A. = 9.72797 log sin ½ Az. = 9.74478
L. App. T., Oct. 11 = 7^h 41^m 30^s A. M. ½ Az. = 33° 45′
Eq. of T. = − 13^m 3^s Az. = S 68° E
Fig. 16 { L. M. T., Oct. 11 = 7^h 28^m 27^s A. M. Or = N 112° E
G. M. T., Oct. 11 = 11^h 54^m 27^s A. M.
Diff. = 4^h 26^m 0^s
Long. = 66° 30′ W

Computation for H. A. and Az. at Second Sight

Chron. = 3^h 3^m 39^s
Error (fast) = − 1^m 48^s
G. M. T., Oct. 11 = 3^h 1^m 51^s

☉ Decl., Oct. 11 = S 6° 48′ 22″ Change in 1^h = 57″
Corr. for 3^h = + 2′ 51″ ×3
Corr. Decl. = S 6° 51′ 13″ Corr. = 171″
P. D. = 96° 51′ 13″ Or = 2′ 51″

Eq. of T., Oct. 11 =	$13^m\ 3^s$	Change in 1^h =	$.651^s$
Corr. for 3^h =	$+\ \ 2^s$		$\times 3$
Corr. Eq. of T. =	$13^m\ 5^s\ (-)$	Corr. =	1.953^s

The latitude to be used in calculating the longitude at second sight is the latitude determined by dead reckoning.

Lat. at first Obs. =	41° 41′ N	
D. Lat. for S 58½° W, 51 mi. =	26.7′ S	Dep. = 43.5′ W
Lat. at second Obs. =	41° 14.3′ N	

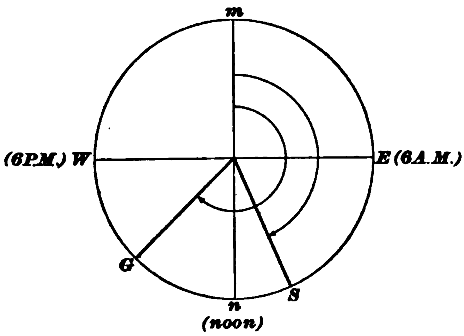


Fig. 17

Obs. Alt. ☉̲ =	38° 43′ 10″			
I. E. =	− 1′ 40″			
	38° 41′ 30″			
Dip =	− 6′ 36″			
	38° 34′ 54″			
S. D. =	+ 16′ 3″			
	38° 50′ 57″			
Par. Ref. =	− 1′ 4″			
a =	38° 49′ 53″	....	sec =	.10847
p =	96° 51′ 13″	cosec = .00311		
l =	41° 14′ 18″	sec = .12379	sec =	.12379
	2)176° 55′ 24″			
S =	88° 27′ 42″	cos = 8.42887	cos =	8.42887
$S-a$ =	49° 37′ 49″	sin = 9.88189		
$p-S$ =	8° 23′ 31″	....	cos =	9.99532
		2)18.43766		2)18.65645

log sin ½ H. A. =	9.21883	log sin ½ Az. =	9.32822
L. A. T., Oct. 11 =	$10^h\ 43^m\ 47^s$ A. M.	½ Az. =	12° 18′
Eq. of T. =	$-\ \ 13^m\ 5^s$	Az. =	S 24° 36′ E
Fig. 17 { L. M. T., Oct. 11 =	$10^h\ 30^m\ 42^s$ A. M.	Or =	N 155° 24′ E
G. M. T., Oct. 11 =	$15^h\ 1^m\ 51^s$ A. M.		
Diff. =	$4^h\ 31^m\ 9^s$		
Long. =	67° 47′ 15″ W		

Solution by St. Hilaire's Method.—In calculating the altitude at first sight use the latitude and longitude by dead reckoning; for second sight use the latitude and longitude at first sight corrected for run between observations. In this case declination is south or negative and latitude is north or positive; hence, A becomes negative.

Calculation for Altitude at First Sight

G. M. T., Oct. 10 = $23^h\ 54^m\ 27^s$
Eq. of T. = $+\ 13^m\ 3^s$
G. A. T. = $24^h\ 7^m\ 30^s$
Long. in time (66° 28′ W) = $-\ 4^h\ 25^m\ 52^s$
L. A. T. = $19^h\ 41^m\ 38^s$
H. A. = $4^h\ 18^m\ 22^s$
Or = 64° 35′ 30″

cos H. A. 64° 35′ 30″ = 9.63253
sin l 41° 41′ = 9.82283 cos l = 9.87322
sin d 6° 48′ 16″ = 9.07365 (−) cos d = 9.99693
log A = 8.89648 log B = 9.50268
A = .07879 (−) B = .31819
A = −.07879
Nat. sin $a = A + B$ = .23940
Whence, a = 13° 51′ 4″

Obs. Alt. ⊖ = 13° 49′ 44
Cal. Alt. ⊖ = 13° 51′ 4″
Alt. Diff. = 1′ 20″
Or = 1.3 mi. *from* observed body

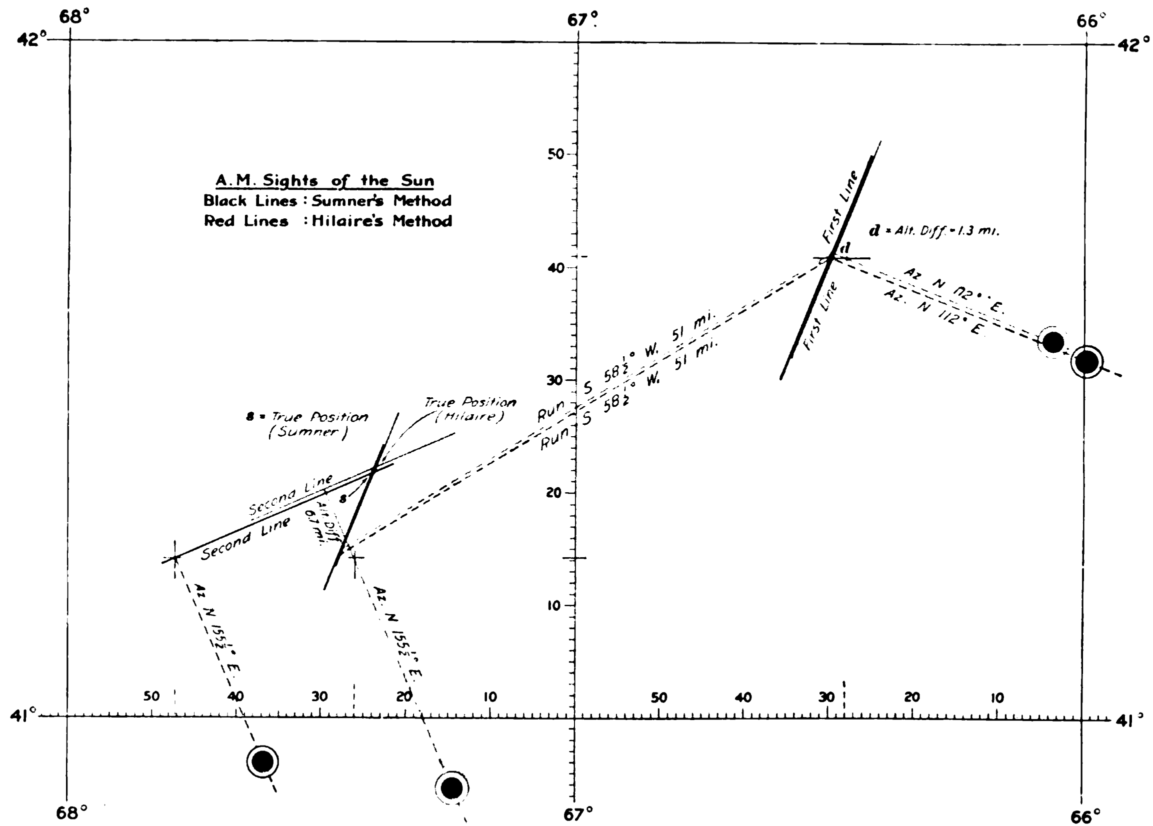
Long. at first sight = 66° 28′ W
D. Long. = 58′ W by Traverse Tables
Long. at second sight = 67° 26′ W

Lat. 41° 14′ 18″ N and Long. 67° 26′ W should be used in calculating the altitude at second sight.

Calculation for Altitude at Second Sight

G. M. T., Oct. 11 = $3^h\ 1^m\ 51^s$
Eq. of T. = $+\ 13^m\ 5^s$
G. A. T. = $3^h\ 14^m\ 56^s$
Long. (67° 26′ W) in time = $4^h\ 29^m\ 44^s$
L. A. T. = $22^h\ 45^m\ 12^s$
H. A. = $1^h\ 14^m\ 48^s$
Or = 18° 42′

cos H. A. 18° 42′ = 9.97645
sin l 41° 14′ 18″ = 9.81901 cos l = 9.87621
sin d 6° 51′ 13″ = 9.07676 (−) cos d = 9.99689
log A = 8.89577 log B = 9.84955
A = .07866 (−) B = .70722
A = −.07866
Nat. sin $a = A + B$ = .62856
Whence, a = 38° 56′ 38″



A.M. Sights of the Sun
Black Lines : Sumner's Method
Red Lines : Hilaire's Method
First Line
d = Alt. Diff. = 1.3 mi.
Az. N 112° E.
Run S 58½° W. 51 mi.
True Position (Hilaire)
8 = True Position (Sumner)
Second Line
Alt. Diff. 6.1 mi.
Az. N 155½° E.
68°
67°
66°
42°
41°

Fig. 18

Obs. Alt. ⊖ = 38° 49′ 53″
Cal. Alt. ⊖ = 38° 56′ 38″
Alt. Diff. = 6′ 45″
Or = 6.7 mi. *from* observed body

The plotting on the chart of each system of lines is now performed in the usual manner. Care should be taken when transferring the first line parallel with itself to do so with utmost precision. A slight error in the transfer of lines for run may cause a considerable error in the final fix. In this case the true position at second observation by Sumner's method is found to be Lat. 41° 21′ 45″ N and Long. 67° 24′ W, while the true position by Hilaire's method is almost identical, being Lat. 41° 22′ 15″ N and 67° 23′ 45″ W as shown on chart, Fig. 18.

Example 2.—October 4, 1914, about 9 o'clock in the morning, an altitude of the sun's lower limb was taken and found to be 16° 57′. Index error = +3′. Height of eye = 45 feet. The chronometer at the instant of measuring the altitude indicated Greenwich mean time to be $9^h\ 10^m\ 20^s$, but the chronometer was $1^m\ 48^s$ fast. Position by dead reckoning was latitude 60° 54′ N, longitude 2° 50′ W. Early in the afternoon, another sight was taken when the altitude was found to be 18° 57′; at that instant the chronometer time was $2^h\ 38^m\ 50^s$. Between observations the ship sailed S 81° W, 39 miles, and S 84° W, 38 miles. Find the ship's true position at the time of the second observation, both by Sumner's and by St. Hilaire's methods.

Solution by Sumner's Method.—

Computation for H. A. and Az. at First Sight

Approx. L. M. T., Oct. 4 = $9^h\ 0^m\ 0^s$ A. M.
Long. W in time = + $11^m\ 20^s$
Approx. G. D., Oct. 4 = $9^h\ 11^m\ 20^s$ A. M.

Chron. = $9^h\ 10^m\ 20^s$
Error = − $1^m\ 48^s$
G. M. T., Oct. 4 = $9^h\ 8^m\ 32^s$ A. M.
Or, Oct. 3 = $21^h\ 8^m\ 32^s$

Decl., Oct. 4 = S 4° 7′ 31″ | Change in 1^h = 58″
Corr. for 2.9^h = − 2′ 48″ | ×2.9
Corr. Decl. = S 4° 4′ 43″ | Corr. = 168.2″ = 2′ 48″
90° 0′ 0″
P. D. = 94° 4′ 43″

Eq. of T., Oct. 4 = $11^m\ 3^s$ | Change in 1^h = $.772^s$
Corr. for 2.9^h = − 2^s | 2.9^s
Corr. Eq. of T. = $11^m\ 1^s$ (−) | Corr. = 2.2388^s

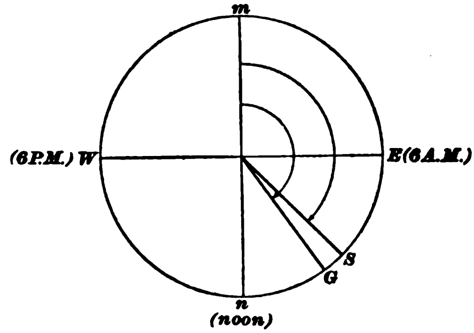


FIG. 19

Obs. Alt. $\underline{\odot}$ =	16° 57′ 0″				
I. E. =	+ 3′ 0″				
	17° 0′ 0″				
Dip =	− 6′ 36″				
	16° 53′ 24″				
S. D. =	+ 16′ 1″				
	17° 9′ 25″				
Ref. Par. =	− 2′ 58″				
a =	17° 6′ 27″			sec =	.01966
p =	94° 4′ 43″	cosec =	.00110		
l =	60° 54′ 0″	sec =	.31306	sec =	.31306
	2)172° 5′ 10″				
S =	86° 2′ 35″	cos =	8.83889	cos =	8.83889
$S-a$ =	68° 56′ 8″	sin =	9.96997		
$p-S$ =	8° 2′ 8″			cos =	9.99572
			2)19.12302		2)19.16733
		log sin ½ H. A. =	9.56151	log sin ½ Az. =	9.58366
		L. A. T. =	9^h 9^m 4^s A. M.	½ Az. =	22° 33′
		Eq. of T. =	− 11^m 1^s	Az. =	S 45° E
Fig. 19		L. M. T., Oct. 4 =	8^h 58^m 3^s A. M.	Or =	N 135° E
		G. M. T., Oct. 4 =	9^h 8^m 32^s A. M.		
		Diff. =	10^m 29^s		
		Long. =	2° 37′ 15″ W		

Computation for H. A. and Az. at Second Sight

Chron. = 2^h 38^m 50^s
Error = − 1^m 48^s
G. M. T., Oct. 4 = 2^h 37^m 2^s

⊙ Decl. Oct. 4 =	S 4° 7′ 31″	Change in 1^h =	58″
Corr. for 2.6^h =	2′ 31″		×2.6
Corr. Decl. =	S 4° 10′ 2″	Corr. =	150.8″
P. D. =	94° 10′ 2″	Or =	2′ 31″
Eq. of T., Oct. 4 =	11^m 3^s	Change in 1^h =	$.772^s$
Corr. for 2.6^h =	+ 2^s		×2.6
Corr. Eq. of T. =	11^m 5^s (−)	Corr. =	2.0072^s

TRAVERSE

Courses	Dist.	D. Lat.		Dep.	
		N	S	E	W
S 81° W	39	——	6.1	——	38.5
S 84° W	38	——	4.0	——	37.8

D. Lat. = 10.1′ S Dep. = 76.3′ W

Lat. at first Obs. = 60° 54′ N
D. Lat. = 10.1′ S
Lat. at second Obs. = 60° 43.9′ N

Use the dead-reckoning latitude in computing the longitude at second observation.

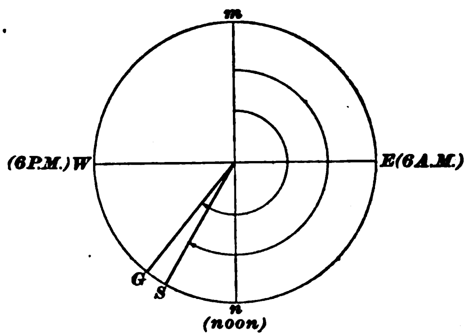


FIG. 20

Obs. Alt. $\underline{\odot}$ =	18° 57′ 0″				
I. E. =	+ 3′ 0″				
	19° 0′ 0″				
Dip =	− 6′ 36″				
	18° 53′ 24″				
S. D. =	+ 16′ 1″				
	19° 9′ 25″				
Ref. Par. =	− 2′ 38″				
a =	19° 6′ 47″			sec =	.02463
p =	94° 10′ 2″	cosec =	.00115		
l =	60° 43′ 54″	sec =	.31078	sec =	.31078
	2)174° 0′ 43″				
S =	87° 0′ 21″	cos =	8.71795	cos =	8.71795
$S-a$ =	67° 53′ 34″	sin =	9.96684		
$p-S$ =	7° 9′ 41″			cos =	9.99660
			2)18.99672		2)19.04996
		log sin ½ H. A. =	9.49836	log sin ½ Az. =	9.52498
		L. A. T., Oct. 4 =	2h 26m 54s P. M.	½ Az. =	19° 34′
		Eq. of T. =	− 11m 5s	Az. =	S 39° W
Fig. 20		L. M. T., Oct. 4 =	2h 15m 49s	Or =	N 141° W
Fig. 20		G. M. T., Oct. 4 =	2h 37m 2s		
		Diff. =	21m 13s		
		Long. =	5° 18′ 15″ W		

SOLUTION BY ST. HILAIRE'S METHOD.—In calculating the altitude at first sight use the latitude and longitude by dead reckoning for the instant of observing the altitude, as in the preceding example. In calculating the altitude at second sight use the latitude and longitude at second sight as found by dead reckoning.

Calculations for Altitude at First Sight

$$
\begin{aligned}
\text{G. M. T., Oct. } 3 &= 21^h\ \ 8^m\ 32^s \\
\text{Eq. of T.} &= \underline{\quad\ 11^m\ \ 1^s} \\
\text{G. A. T.} &= 21^h\ 19^m\ 33^s \\
\text{Long. in time (W)} &= \underline{-\quad 11^m\ 20^s} \\
\text{L. A. T.} &= 21^h\ \ 8^m\ 13^s \\
\text{H. A.} &= \ \ 2^h\ 51^m\ 47^s \\
\text{Or} &= 42^\circ\ 56'\ 45''
\end{aligned}
$$

$$
\begin{array}{lr}
 & \cos \text{H. A. } 42^\circ\ 56'\ 45'' = \ \ 9.86451 \\
\sin l\ 60^\circ\ 54' = 9.94140 & \cos l = \ \ 9.68694 \\
\sin d\ 4^\circ\ 4'\ 43'' = \underline{8.85202}\ (-) & \cos d = \ \ \underline{9.99890} \\
\log A = 8.79342 & \log B = \ \ 9.55035 \\
A = \ .06215\ (-) & B = \quad .35510 \\
 & A = \underline{-.06215} \\
 & \text{Nat. } \sin a = A + B = \quad .29295 \\
 & \text{Whence, } a = 17^\circ\ 2'\ 4''
\end{array}
$$

$$
\begin{aligned}
\text{Obs. Alt. } \ominus &= 17^\circ\ \ 6'\ 27'' \\
\text{Cal. Alt. } \ominus &= \underline{17^\circ\ \ 2'\ \ \ 4''} \\
\text{Alt. Diff.} &= \qquad 4'\ 23''
\end{aligned}
$$

Or = 4.4 mi. *toward* observed body

$$
\begin{aligned}
\text{Long. at first sight} &= 2^\circ\ 50'\ \text{W} \\
\text{D. Long.} &= \underline{2^\circ\ 37'\ \text{W}} \\
\text{Long. at second sight} &= 5^\circ\ 27'\ \text{W}
\end{aligned}
$$

Lat. 60° 43.9′ N and Long. 5° 27′ W should be used in calculating the altitude at second sight

Calculation for Altitude at Second Sight

$$
\begin{aligned}
\text{G. M. T., Oct. } 4 &= \ \ 2^h\ 37^m\ \ 2^s \\
\text{Eq. of T.} &= \underline{+\ \ 11^m\ \ 5^s} \\
\text{G. A. T.} &= \ \ 2^h\ 48^m\ \ 7^s \\
\text{Long. in time (W)} &= \underline{-\ \ 21^m\ 48^s} \\
\text{L. A. T.} &= \ \ 2^h\ 26^m\ 19^s \\
\text{H. A.} &= 36^\circ\ 34'\ 45''
\end{aligned}
$$

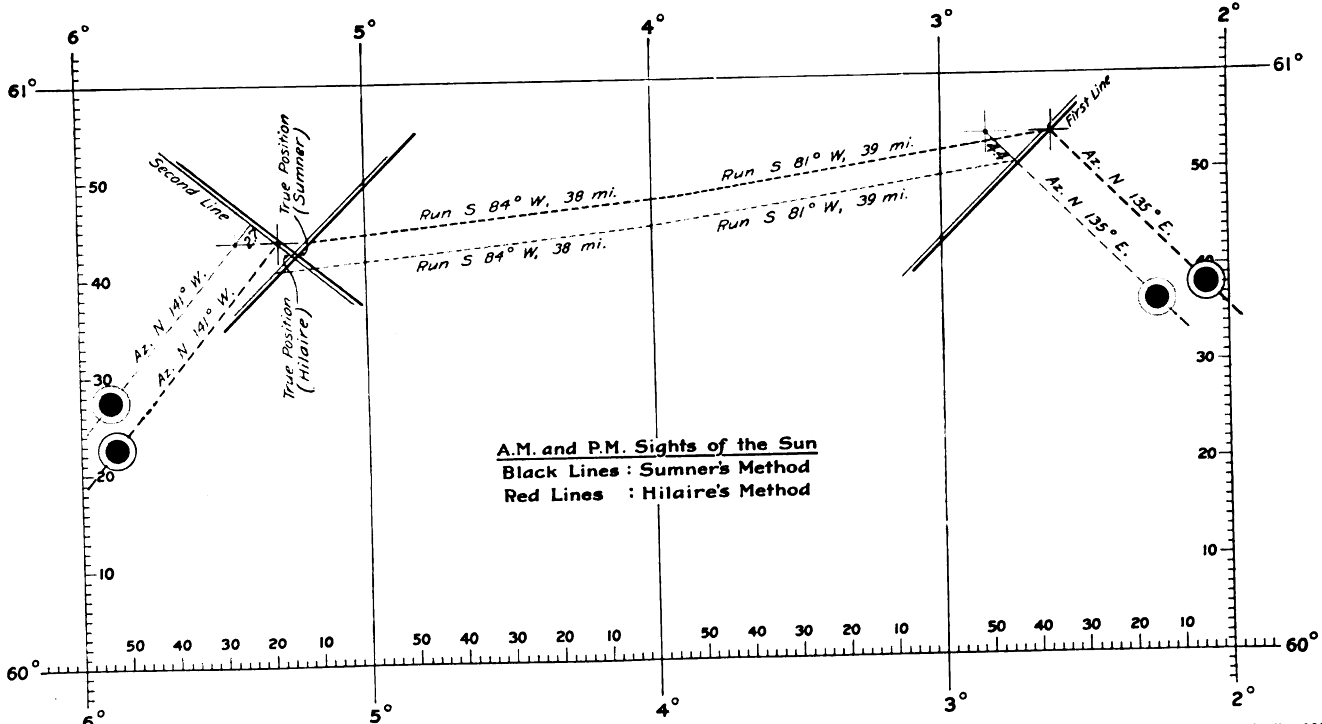


Fig. 21

§ 17 197B

$$
\begin{array}{rlrl}
 & & \cos \text{H. A. } 36° 34' 45'' = & 9.90473 \\
\sin l\ 60° 43.9' = & 9.94068 & \cos l = & 9.68922 \\
\sin d\ 4° 10' 2'' = & \underline{8.86134}\ (-) & \cos d = & 9.99885 \\
\log A = & 8.80202 & \log B = & 9.59280 \\
A = & .06339\ (-) & B = & .39156 \\
 & & A = & \underline{-.06339} \\
 & & \text{Nat. } \sin a = A + B = & .32817 \\
 & & \text{Whence, } a = & 19° 9' 28''
\end{array}
$$

$$
\begin{array}{rl}
\text{Obs. Alt. } \ominus = & 19° 6' 47'' \\
\text{Cal. Alt. } \ominus = & \underline{19° 9' 28''} \\
\text{Alt. Diff.} = & \quad 2' 41''
\end{array}
$$

Or = 2.7 mi. *from* observed body

As will be seen from the chart, Fig. 21, the true position at the second observation is about 60° 42.5′ N and 5° 15′ W by either method.

36. Observations Near Meridian.—That St. Hilaire's method can be used with advantage for sights taken near the meridian will be shown in the examples that follow. For comparison, the sights are worked by the ordinary methods explained in *Latitude* and by the method of St. Hilaire.

EXAMPLE.—On July 12, 1914, in latitude 50° N and longitude 40° W, by dead reckoning, an altitude of the sun's lower limb taken near the meridian was 61° 42′ 50″. The true bearing of the sun was S 3° 30′ E. Index error = +2′ 40″, and height of eye = 15 feet. The chronometer indicated $2^h\ 41^m\ 51^s$, its error on Greenwich mean time being $2^m\ 42^s$ fast. Find the latitude in by reduction to the meridian and by St. Hilaire's method.

SOLUTION BY REDUCTION TO THE MERIDIAN.—

$$
\begin{array}{rl}
\text{Chron.} = & 2^h\ 41^m\ 51^s \\
\text{Error (fast)} = & \underline{-\quad 2^m\ 42^s} \\
\text{G. M. T., July } 12 = & 2^h\ 39^m\ 9^s \text{ P. M.} \\
\text{Or, July } 12 = & 14^h\ 39^m\ 9^s \text{ A. M.} \\
\text{Long. (40° W) in time} = & \underline{2^h\ 40^m\ 0^s} \\
\text{L. M. T., July } 12 = & 11^h\ 59^m\ 9^s \\
\text{Eq. of T.} = & \underline{-\quad 5^m\ 19^s} \\
\text{L. App. T., July } 12 = & 11^h\ 53^m\ 50^s \\
\text{Interval from noon} = & \quad 6^m\ 10^s = \text{H. A. easterly}
\end{array}
$$

$$
\begin{array}{rlrl}
\odot \text{ Decl., July } 12 = & \text{N } 22° 4' \ 1.4'' & \text{Change in } 1^h = & 20.26'' \\
\text{Corr. for } 2.65^h = & \underline{-\qquad 53.7''} & & \underline{\times 2.65} \\
\text{Corr. Decl.} = & \text{N } 22° 3' \ 7.7'' & \text{Corr.} = & 53.6890'' \\
\text{Eq. of T.} = & 5^m\ 18.02^s & \text{Change in } 1^h = & .328^s \\
\text{Corr. for } 2.65^h = & \underline{+\quad .87^s} & & \underline{\times 2.65} \\
\text{Corr. Eq. of T.} = & 5^m\ 18.89^s & \text{Corr.} = & .86920^s
\end{array}
$$

Correct the observed altitude and find from pages 162 and 163 of Nautical Tables the correction required to obtain the true meridian altitude.

The first table gives 2.5
The second table gives ×38
Product = 95.0″
Whence, Corr. = + 1′ 35″

Obs. Alt. $\underline{\odot}$ = 61° 42′ 50″
I. E. = + 2′ 40″
61° 45′ 30″
Dip = − 3′ 48″
61° 41′ 42″
S. D. = + 15′ 46″
61° 57′ 28″
Par. Ref. = − 27″
True Alt. $\ominus$ = 61° 57′ 1″
Corr. = + 1′ 35″
True Mer. Alt. = 61° 58′ 36″
90° 0′ 0″
$\odot$ Z. D. = 28° 1′ 24″ N
$\odot$ Decl. = 22° 3′ 8″ N
Lat. = 50° 4′ 32″ N

Solution by St. Hilaire's Method.—

G. M. T., July 12 = $2^h\ 39^m\ 9^s$
Eq. of T. = − $5^m\ 19^s$
G. App. T., July 12 = $2^h\ 33^m\ 50^s$
Or, July 12 = $14^h\ 33^m\ 50^s$ A. M.
Long. (40° W) in time = $2^h\ 40^m\ 0^s$
L. App. T., July 12 = $11^h\ 53^m\ 50^s$ A. M.
Whence, H. A. = $6^m\ 10^s$
Or, H. A. = 1° 32′ 30″

cos H. A. 1° 32′ 30″ = 9.99984

sin l 50° = 9.88425	cos l = 9.80807
sin d 22° 3′ 8″ = 9.57455	cos d = 9.96700
log A = 9.45880	log B = 9.77491
A = .2876	B = .59554
	A = .28760

Nat. sin $a = A + B$ = .88314
Whence, a = 62° 1′ 26″

Obs. Alt. $\ominus$ = 61° 57′ 1″
Cal. Alt. $\ominus$ = 62° 1′ 26″
Alt. Diff. = 4′ 25″
Or = 4.4 mi. *from* observed body

37. The latitude found by using the second method of reduction to the meridian in this case is 50° 4.5′ N. By using the same data and calculating the line of position by St. Hilaire's method, the resulting latitude agrees within ½ mile of that previously obtained, as shown in Fig. 22. From the dead-

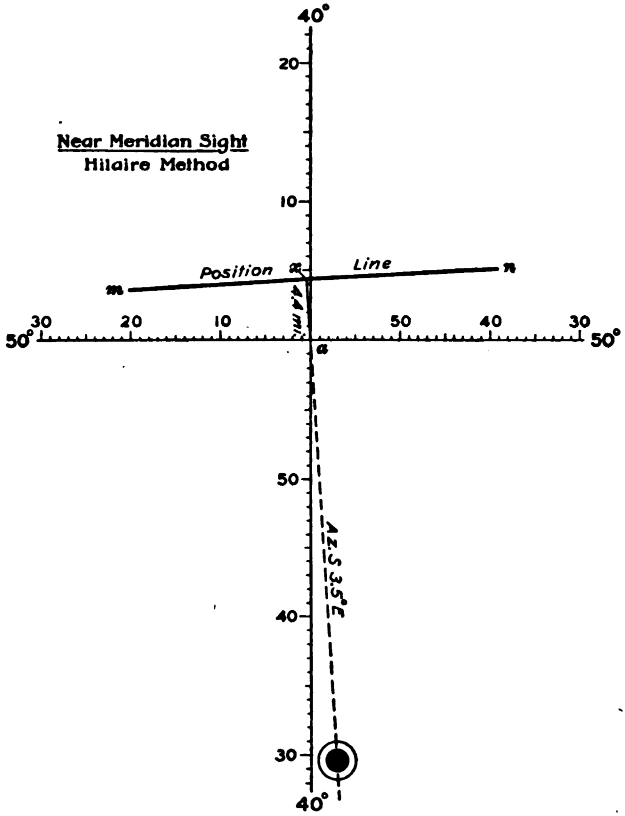


FIG. 22

reckoning position a is plotted the true bearing of the sun S 3.5° E. Since the observed altitude is less than the calculated, the difference is laid off toward the north or away from the sun, fixing the position of the ship at x on the line of position $m\ n$. As stated, this position coincides very nearly with that obtained by the ordinary method and serves to

illustrate the utility of the St. Hilaire method for sights taken close to the meridian.

38. In the example that follows, which is identical to that worked by the *M* and *N* method in example 2, Art. **30** of

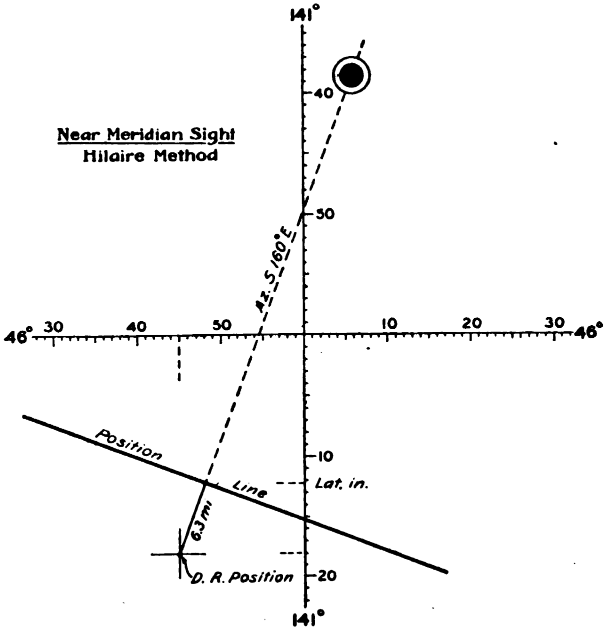


Fig. 23

Latitude, a fix is obtained by the St. Hilaire method very close to that obtained by the *M* and *N* method.

Example.—Position by dead reckoning, latitude 46° 18′ S, longitude 140° 45′ E. Hour angle is $47^m\ 28^s$, or 11° 52′ easterly; declination is S 6° 7′ 25″; observed true altitude is 48° 38′ 36″; azimuth is S 160° E. Find line of position and latitude by St. Hilaire's method.

Solution.—	cos H. A. 11° 52′ = 9.99062
sin l 46° 18′ = 9.85912	cos l = 9.83940
sin d 6° 7′ 25″ = 9.02806	cos d = 9.99752
log A = 8.88718	log B = 9.82754
A = .07712	B = .67227
	A = .07712
	Nat. sin $a = A + B$ = .74939
	Whence, a = 48° 32′ 16″

Obs. Alt. ⊖ =	48° 38′ 36″
Cal. Alt. ⊖ =	48° 32′ 16″
Alt. Diff. =	6′ 20″
	Or = 6.3 mi. *toward* observed body

Plot the dead-reckoning position on chart, Fig. 23, and from this point lay off the altitude difference of 3.3 mi. along the bearing of the sun. This will give a line of position running as shown, the resulting latitude being 46° 12.1′ S, which agrees very nearly with the latitude obtained by the *M* and *N* method.

39. The following example is given of an observation taken near the meridian and worked by St. Hilaire's method, in which the altitude difference is very large. Yet the resulting latitude comes out very close to that worked by the ordinary method of reduction to the meridian. The data used are the same as in Examination Question 16 of *Latitude*.

EXAMPLE.—On July 16, 1899, an altitude of the sun's lower limb, observed near the meridian, was 36° 47′ 40″, the observer facing north. The index error = +2′ 21″. Height of eye = 13 feet. The interval of time from the instant of observation to apparent noon was found to be $10^m\ 18^s$. The declination (corrected) was N 21° 22′ 6″. The latitude in, according to dead reckoning, was $30\frac{1}{2}$° S. Find, by St. Hilaire's method, the latitude in, the sun's azimuth being S 177° E.

SOLUTION.— H. A. = $10^m\ 18^s$

		Or = 2° 34′ 30″ cos =	9.99956
sin *l* 30° 30′ =	9.70547 (−)	cos *l* =	9.93532
sin *d* 21° 22′ 6″ =	9.56153	cos *d* =	9.96907
log *A* =	9.26700	log *B* =	9.90395
A =	.18493 (−)	*B* =	.80158
		A = −	.18493
		Nat. sin *a* = *A* + *B* =	.61665
		Whence *a* =	38° 4′ 18″

Obs. Alt. $\underline{\odot}$ =	36° 47′ 40″
I. E. = +	2′ 21″
	36° 50′ 1″
Dip = −	3′ 32″
	36° 46′ 29″
⊙ S. D. = +	15′ 46″
	37° 2′ 15″
Par. Ref. = −	1′ 9″
Obs. Alt. ⊖ =	37° 1′ 6″

Cal. Alt. ⊖ =	38° 4′ 18″
Obs. Alt. ⊖ =	37° 1′ 6″
Alt. Diff. =	1° 3′ 12″
Or =	63.2 mi.,
	from observed body

In Fig. 24 is shown the line of position obtained by solving the preceding example according to St. Hilaire's method. The resulting latitude comes within $\frac{1}{10}$ mile of that found by reduction to the meridian, illustrating the utility of the St. Hilaire method to all kinds of sights.

40. It is not to be inferred from the examples just shown that sights taken close to the meridian should be worked always

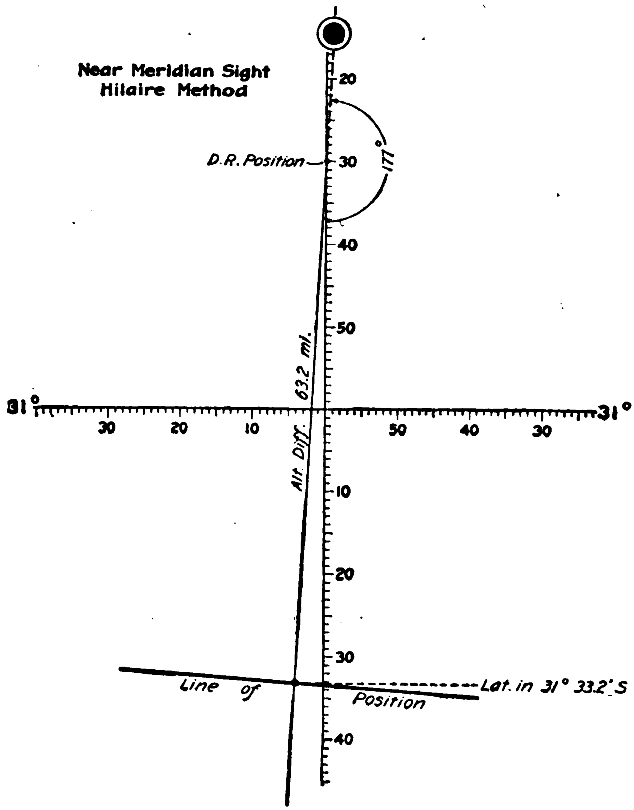


Fig. 24

by the St. Hilaire method. It is quicker to work such sights by the method of reduction to the meridian. The object of these examples is simply to show that such sights can be worked by the new method with results quite as satisfactory and trustworthy.

41. Attention is also called to the fact that it is not necessary to plot lines of position deduced from sights for latitude near the meridian. Instead when the altitude difference is found it may be entered with the azimuth, or the reverse of the azimuth, as the case may be, in the Traverse Tables as course and distance run when the difference of latitude corresponding is applied direct to the latitude by dead reckoning. Thus, in the preceding example, by entering the Traverse Tables with S 3° W (=S 177° E) and 63.2 as distance the corresponding difference of latitude is 63.1′ S. Applying this to the dead-reckoning latitude the result is as follows:

$$\begin{array}{r@{}l} \text{D. R. Lat.} = & 30°\ 30'\ \ \text{S} \\ \text{D. Lat.} = & \underline{\ \ 1°\ \ 3.1'\,\text{S}} \\ \text{Lat. in} = & 31°\ 33.1'\,\text{S} \end{array}$$

42. Application of Method to Stars.—The St. Hilaire method is applicable to observations of stars as well as to sights of the sun. The altitude is calculated in exactly the same way, the star's hour angle being used instead of the apparent time. By applying the star's right ascension to the local sidereal time the hour angle of the star is readily obtained. As an illustration the example given in Art. 22, *Sumner's Method*, will be worked according to the St. Hilaire method. The data given in this example are as follows:

EXAMPLE 1.—Simultaneous observations were made of the stars Regulus and Aldebaran on March 19, 1899, at 8:30 P. M. The altitude of Regulus east of the meridian was 46° 19′ 20″. The altitude of Aldebaran west of the meridian was 34° 3′. The chronometer at instant of sights was $11^h\ 1^m\ 34^s$, the error on Greenwich mean time being $5^m\ 21^s$ slow. Height of eye = 29 feet and index error = +4′ 10″. Position by dead reckoning was latitude = 50° 5′ N., longitude = 40° 33′ W. The azimuth of Aldebaran was S 73° 50′ W and of Regulus S 40° E.

SOLUTION.—

Computation for Altitude of Regulus

$$\begin{array}{r@{}l} \text{Chron.} = & 11^h\ \ 1^m\ 34^s \\ \text{Error (slow)} = & \underline{+\ \ \ \ 5^m\ 21^s} \\ \text{G. M. T., Mch. 19} = & 11^h\ \ 6^m\ 55^s \\ \text{R. A. M. S.} = & \underline{23^h\ 49^m\ \ 5^s} \\ \text{G. Sid. T., Mch. 19} = & 34^h\ 56^m\ \ 0^s \end{array} \qquad \begin{array}{r@{}l} \text{Sid. T., G. M. N.} = & 23^h\ 47^m\ 15.5^s \\ \text{Corr. for } 11^h\ 7^m = & \underline{+\ \ \ \ 1^m\ 49.6^s} \\ \text{R. A. M. S.} = & 23^h\ 49^m\ \ 5.1^s \\ * \text{ Decl.} = & \text{N } 12°\ 27'\ 35'' \\ * \text{ R. A.} = & 10^h\ 3^m\ 0^s \end{array}$$

Or, Mch. 20 = $10^h\ 56^m\ 0^s$	Obs. Alt. ✳ = 46° 19′ 20″
Long. (40° 33′ W) = $2^h\ 42^m\ 12^s$	I. E. = + 4′ 10″
L. Sid. T., Mch. 20 = $8^h\ 13^m\ 48^s$	46° 23′ 30″
✳ R. A. = $10^h\ 3^m\ 0^s$	Dip = − 5′ 17″
✳ H. A. = $1^h\ 49^m\ 12^s$	46° 18′13″
Or = 27° 18′	Ref. = − 54″
	True Obs. a = 46° 17′ 19″

	cos H. A. 27° 18′ = 9.94871
sin l 50° 5′ = 9.88478	cos l = 9.80731
sin d 12° 27′ 35″ = 9.33396	cos d = 9.98965
log A = 9.21874	log B = 9.74567
A = .16547	B = .55676
	A = .16547
	Nat. sin $a = A + B$ = .72223
	Whence, a = 46° 14′ 21″

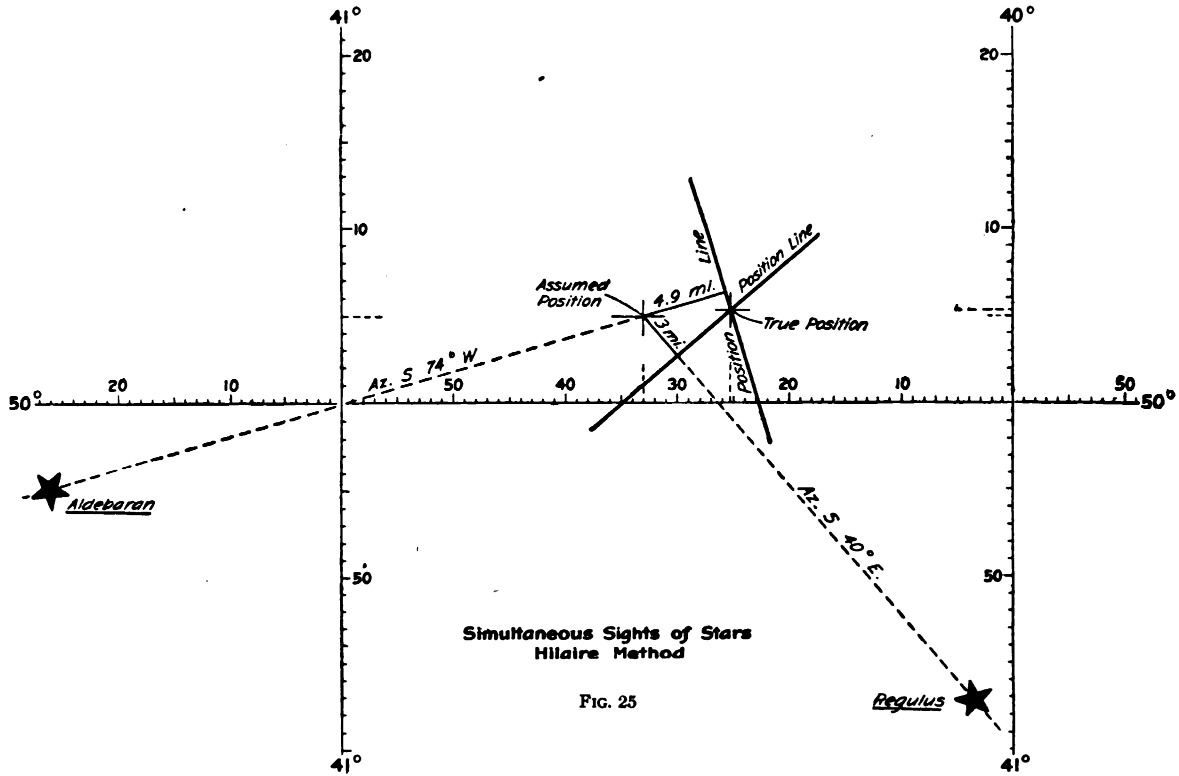
Obs. Alt. ✳ Regulus = 46° 17′ 19″
Cal. Alt. ✳ Regulus = 46° 14′ 21″
Alt. Diff. = 2′ 58″
Or = 3 mi. *toward* observed body

Computation for Altitude of Aldebaran

Using the same data for finding the local sidereal time as in the case of Regulus, the altitude of Aldebaran is worked out thus: The right ascension and declination of Aldebaran are, respectively, $4^h\ 30^m\ 8^s$ and N 16° 18′ 24″.

L. Sid. T., Mch. 20 = $8^h\ 13^m\ 48^s$	Obs. Alt. ✳ = 34° 3′ 0″
✳ R. A. = $4^h\ 30^m\ 8^s$	I. E. = + 4′ 10″
✳ H. A. = $3^h\ 43^m\ 40^s$	34° 7′ 10″
Or = 55° 55′	Dip = − 5′ 17″
	34° 1′ 53″
	Ref. = − 1′ 24″
	True Obs. a = 34° 0′ 29″

	cos H. A. 55° 55′ = 9.74850
sin l 50° 5′ = 9.88478	cos l = 9.80731
sin d 16° 18′ 24″ = 9.44836	cos d = 9.98217
log A = 9.33314	log B = 9.53798
A = .21535	B = .34513
	A = .21535
	Nat. sin $a = A + B$ = .56048
	Whence, a = 34° 5′ 20″



Simultaneous Sights of Stars
Hilaire Method

Fig. 25

Obs. Alt. ✱ Aldebaran = 34° 0′ 29″
Cal. Alt. ✱ Aldebaran = 34° 5′ 20″
Alt. Diff. = 4′ 51″
Or = 4.9 mi. *from* observed body

43. By plotting the azimuths of the two stars and measuring off from the assumed, or dead-reckoning, position (Lat. 50° 5′ N, Long. 40° 33′ W), the altitude difference in each case, the required lines of position are obtained as shown in Fig. 25.

The intersection of the two lines gives the true position as latitude 50° 5′ 20″ N and longitude 40° 25′ 20″ W, which agrees exactly with the true position found by the tangent method and shown in Fig. 22 of *Sumner's Method.*

EXAMPLE 2.—April 26, 1914, P. M., when latitude by dead reckoning was 29° 03′ N, and the longitude, 76° 30′ W, simultaneous altitudes of the stars α Virginis (Spica) bearing southward and eastward and β Orionis (Rigel) bearing southward and westward were observed. The sextant altitude of Spica is 21° 18′ 10″, of Rigel is 17° 49′ 0″. Index error = +2′ 10″ and height of eye = 45 feet. The local mean time was about 7 P. M. The chronometer at the instant of observation indicated Greenwich mean time to be $12^h\ 10^m\ 48^s$, but its error was $5^m\ 12^s$ slow. The sidereal time, G. M. N. or R. A. M. S. for April 26, 1914, is $2^h\ 14^m\ 34^s$. Declination and right ascension of Spica are S 10° 42′ 52″ and $13^h\ 20^m\ 41^s$, respectively, and of Rigel S 8° 17′ 59″ and $5^h\ 10^m\ 25^s$, respectively. Find the ship's true position by Sumner's method and by the method of St. Hilaire.

SOLUTION BY SUMNER'S METHOD.—

Computation for H. A. and Az. of Spica

Approx. L. M. T., Apr. 26 = $7^h\ 0^m\ 0^s$ P. M.
Long. (W) in time = $5^h\ 6^m\ 0^s$
Approx. G. M. T., Apr. 26 = $12^h\ 6^m\ 0^s$

Chron. =	$12^h\ 10^m\ 48^s$	Sid. time, G. M. N. =	$2^h\ 14^m\ 34^s$
Error (slow) =	+ $5^m\ 12^s$	Corr. for $12^h\ 16^m$ =	+ $2^m\ 1^s$
G. M. T., Apr. 26 =	$12^h\ 16^m\ 0^s$	R. A. M. S. =	$2^h\ 16^m\ 35^s$
R. A. M. S. =	$2^h\ 16^m\ 35^s$		
G. Sid. T., Apr. 26 =	$14^h\ 32^m\ 35^s$		
Obs. Alt. =	21° 18′ 10″	✱ Corr. Decl. =	S 10° 42′ 51.9″
I. E. =	+ 2′ 10″		90° 0′ 0″
	21° 20′ 20″	P. D. =	100° 42′ 51.9″
Dip =	− 6′ 36″		
	21° 13′ 44″		
Ref. =	− 2′ 26″		
True a =	21° 11′ 18″		

a =	21° 11′ 18″			sec =	.03040
p =	100° 42′ 52″	cosec =	.00764		
l =	29° 3′ 0″	sec =	.05839	sec =	.05839
2)	150° 57′ 10″				
S =	75° 28′ 35″	cos =	9.39929	cos =	9.39929
$S-a$ =	54° 17′ 17″	sin =	9.90954		
$p-S$ =	25° 14′ 17″			cos =	9.95643
			2) 19.37486		2) 19.44451
		log sin ½ H. A. =	9.68743	log sin ½ Az. =	9.72225
		✳ H. A. =	$3^h\ 53^m\ 5^s$ E	½ Az. =	32°
		✳ R. A. =	$13^h\ 20^m\ 41^s$	Az. =	S 64° E
		L. Sid. T., Apr. 26 =	$9^h\ 27^m\ 36^s$		
		G. Sid. T., Apr. 26 =	$14^h\ 32^m\ 35^s$		
		Diff. =	$5^h\ 4^m\ 59^s$		
		Long. =	76° 14′ 45″ W		

Computation for H. A. and Az. of Rigel

Greenwich sidereal time is the same as in observation of Spica since observations are simultaneous; on April 26 it was $14^h\ 32^m\ 35^s$.

Obs. Alt. =	17° 49′ 0″	✳ Corr. Decl. =	S 8° 17′ 59″
I. E. =	+ 2′ 10″		90° 0′ 0″
	17° 51′ 10″	P. D. =	98° 17′ 59″
Dip =	− 6′ 36″		
	17° 44′ 34″		
Ref. =	− 2′ 56″		
True a =	17° 41′ 38″		

a =	17° 41′ 38″			sec =	.02104
p =	98° 17′ 59″	cosec =	.00457		
l =	29° 3′ 0″	sec =	.05839	sec =	.05839
2)	145° 2′ 37″				
S =	72° 31′ 18″	cos =	9.47762	cos =	9.47762
$S-a$ =	54° 49′ 40″	sin =	9.91245		
$p-S$ =	25° 46′ 41″			cos =	9.95448
			2) 19.45303		2) 19.51153
		log sin ½ H. A. =	9.72651	log sin ½ Az. =	9.75576
		✳ H. A. =	$4^h\ 17^m\ 31^s$	½ Az. =	34° 44′
		✳ R. A. =	$5^h\ 10^m\ 25^s$	Az. =	S 69° 28′ W
		L. Sid. T., Apr. 26 =	$9^h\ 27^m\ 56^s$		
		G. Sid. T., Apr. 26 =	$14^h\ 32^m\ 35^s$		
		Diff. =	$5^h\ 4^m\ 39^s$		
		Long. =	76° 9′ 45″ W		

SOLUTION BY ST. HILAIRE'S METHOD.—

Computation for Alt. ✳ Spica

G. M. T. $= 12^h\ 16^m\ 0^s$
R. A. M. S. $= \underline{2^h\ 16^m\ 35^s}$
G. Sid. T. $= 14^h\ 32^m\ 35^s$
Long. (W) in time $= \underline{5^h\ 6^m\ 0^s}$
L. Sid. T. $= 9^h\ 26^m\ 35^s$
✳ R. A. $= \underline{13^h\ 20^m\ 41^s}$
✳ H. A. $= 3^h\ 54^m\ 6^s$
Or $= 58°\ 31'\ 30''$

		cos H. A. 58° 31′ 30″ =	9.71777
sin l 29° 3′ =	9.68625	cos l =	9.94161
sin d 10° 42′ 52″ =	9.26931 (−)	cos d =	9.99236
log A =	8.95556	log B =	9.65174
A =	.09027 (−)	B =	.44848
		A =	−.09027
		Nat. sin $a = A + B$ =	.35821
		Whence, a =	20° 59′ 24″

Obs. Alt. ✳ Spica $= 21°\ 11'\ 18''$
Cal. Alt. ✳ Spica $= \underline{20°\ 59'\ 24''}$
Alt. Diff. $= 11'\ 54''$
Or $= 11.9$ mi. *toward* observed body

Computation for Alt. ✳ Rigel

L. Sid. T. $= 9^h\ 26^m\ 35^s$ (same as for Spica)
✳ R. A. $= \underline{5^h\ 10^m\ 25^s}$
✳ H. A. $= 4^h\ 16^m\ 10^s$
Or $= 64°\ 2'\ 30''$

		cos H. A. 64° 2′ 30″ =	9.64119
sin l 29° 3′ =	9.68625	cos l =	9.94161
sin d 8° 17′ 59″ =	9.15943 (−)	cos d =	9.99543
log A =	8.84568	log B =	9.57823
A =	.07009 (−)	B =	.37864
		A =	−.07009
		Nat. sin $a = A + B$ =	.30855
		Whence, a =	17° 58′ 19″

Obs. Alt. ✳ Rigel $= 17°\ 41'\ 38''$
Cal. Alt. ✳ Rigel $= \underline{17°\ 58'\ 19''}$
Alt. Diff. $= 16'\ 41''$
Or $= 16.7$ mi. *from* observed body

The lines of position obtained by the Sumner's and St. Hilaire's methods, respectively, are plotted on chart, Fig. 26. The lines of both

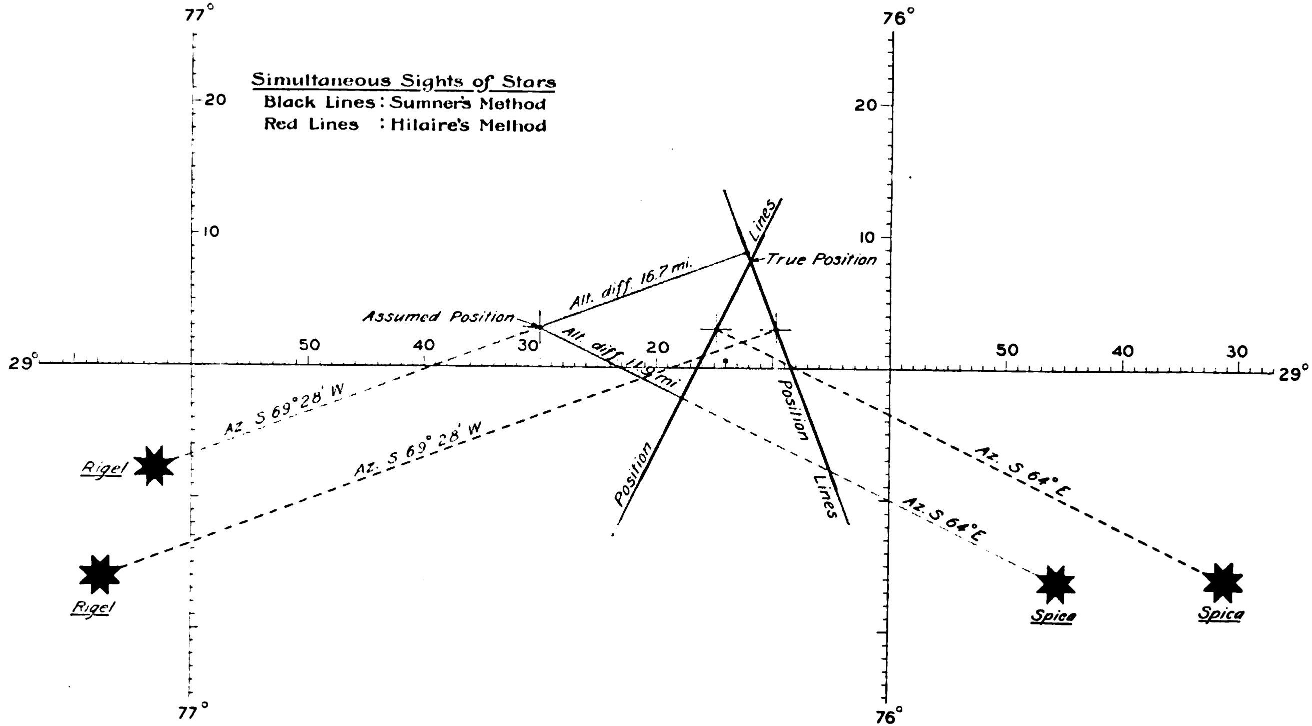

Simultaneous Sights of Stars
Black Lines: Sumner's Method
Red Lines : Hilaire's Method
77°
76°
29°
20
10
50
40
30
Assumed Position
True Position
Alt. diff. 16.7 mi.
Alt. diff. 11.9 mi.
Position
Lines
Az. S 69° 28' W
Az. S 64° E
Rigel
Spica

FIG. 26

methods coincide as do the resulting true positions, the latitude and longitude of the fix being 29° 8′ N. and 76° 12′ W.

44. De Aquino's Tables.*—Attention is called to altitude and azimuth tables compiled by Lieutenant Radler De Aquino, of the Brazilian navy. The purpose of these tables is to furnish a convenient means of finding the altitude and azimuth, corresponding to an assumed latitude and longitude, for navigators who prefer such tables to logarithmic work. Instead of calculating the altitude it may be taken from the Aquino tables and compared with the observed altitude in the usual way. Whether the tables offer any advantage over the method of finding the altitude by the sine-cosine formula is a question that must be decided by the navigator himself. The method of using the tables is fully explained and illustrated by problems worked out in detail by the author.

45. Line of Position Tables.—A collection of tables with this title has recently been published by the Hydrographic Office; they were prepared with the special aim of presenting, in the order in which they are used in practice, all the navigational and mathematical tables, except those of the Nautical Almanac, that are essential for the working of a sight of a celestial body for line of position by the cosine-haversine formula, Marcq St. Hilaire method. The price of the tables is 45 cents a copy.

EXAMPLES FOR PRACTICE

1. On June 30, 1899, in latitude 47° 50′ N and longitude 23° 30′ W, by dead reckoning, the observed altitude of the sun's lower limb was 54° 35′ 50″, the true azimuth being S 57° W. The chronometer at instant of sight indicated $3^h\ 38^m\ 22^s$, its error on Greenwich mean time being $2^m\ 15^s$ slow. Later in the afternoon, when the chronometer read $7^h\ 8^m\ 4^s$, a second altitude of the sun's lower limb measured 21° 53′ 40″, the azimuth then being S 100° 46′ W. Index error $= -3'\ 10''$. Height of eye = 19 feet. Find, by St. Hilaire's method, the true position of the ship at second observation, assuming no run was made between sights. Ans. $\begin{cases} \text{Lat.} = 49°\ 20'\ \text{N} \\ \text{Long.} = 24°\ 1'\ \text{W} \end{cases}$

*The De Aquino Tables are published by J. D. Potter, London, Eng., and may be obtained through the American agents of the publishers, Bliss & Company, 128 Front Street, New York, N. Y.

2. On November 12, 1899, an altitude of the sun's lower limb measured when near the meridian was 56° 32′ 40″. The chronometer read 18^h 10^m 33^s, its error on Greenwich mean time being 3^m 33^s slow. The true azimuth was N 167° W. Index error = +4′ 49″. Height of eye = 33 feet. Position by dead reckoning was latitude 14° 12′ N and longitude 90° 35′ E. Find, by St. Hilaire's method, the correct latitude. Ans. Lat. = 14° 34′ N

3. On Sept. 29, 1899, P. M., when the chronometer indicated 9^h 17^m 58^s, the altitude of the sun's lower limb was 36° 28′ 40″. The true azimuth at sight was S 23° 30′ W. After a run E $\frac{1}{4}$ N, true, 43 miles, a second altitude of the sun measured 18° 34′ 15″ when the chronometer read 11^h 53^m 56^s, the azimuth at that time being S 63° W. The error of the chronometer on Greenwich mean time was 8^m 14^s slow. Index error + = 2′ 57″. Height of eye = 34 feet. The ship's position by dead reckoning was latitude 48° 15′ N and longitude 123° W. Find, by St. Hilaire's method, the true position of the ship.

Ans. $\begin{cases} \text{Lat.} = 48° \ 37' \text{ N} \\ \text{Long.} = 125° \ 35' \text{ W} \end{cases}$

4. On June 15, 1899, A. M., an altitude of the sun's lower limb when near the meridian measured 53° 13′ 10″, the observer facing south. The chronometer read 1^h 4^m 5^s, its error on Greenwich mean time being 50^m 35^s fast. The true azimuth was N 176° E. The ship's assumed position was latitude 58° 50′ N and longitude 173° 56′ 45″ E. Index error = +1′ 26″. Height of eye = 25 feet. Find latitude in, by the St. Hilaire method.

Ans. Lat. = 59° 50′ N

5. On May 19, 1899, P. M., the observed altitude of Jupiter's center, east of the meridian, was 30° 7′ 25″. Simultaneous measurement of the altitude of the star Pollux, west of the meridian, gave it as 23° 39′ 30″. The chronometer reading gave the Greenwich mean time as 18^h 56^m 46^s, its error being 9^m 11^s fast. Height of eye = 33 feet. Index error = +4′ 3″. Position by dead reckoning was uncertain but estimated to be latitude 48° 20′ N and longitude 138° 30′ W. The azimuth of Jupiter was S 10.5° E and the azimuth of Pollux S 106.7° W. Find, by St. Hilaire's method, the true position of the ship.

Ans. $\begin{cases} \text{Lat.} = 48° \ 9.5' \text{ N} \\ \text{Long.} = 139° \ 27' \text{ W} \end{cases}$

6. On December 31, 1899, the observed altitude of the sun's lower limb near the meridian was 53° 57′. The chronometer reading was 11^h 8^m 8^s, its error on Greenwich mean time being 52^m 40^s fast. Estimated position of ship was 13° 45′ N and 150° 15′ W. Index error = +2′ 2″. Height of eye = 25 feet. The sun's true azimuth was N 176° W. Find, by St. Hilaire's method, the latitude in. Ans. Lat. = 12° 40′ N

EXTRACTS FROM NAUTICAL ALMANAC FOR YEAR 1914

(At Greenwich Mean Noon)

Month	Day of Month	The Sun's Apparent Declination	The Sun's Diff. for 1 Hour	Equation of Time to be Subtracted from Mean Time	Diff. for 1 Hour	Semi-Diameter
		° ′ ″	″	m s	s	′ ″
July	5	N 22 51 19.1	−13.46	4 13.16	0.440	15 45.70
	6	22 45 44.0	14.45	4 23.54	0.425	15 45.71
	7	22 39 45.3	15.44	4 33.57	0.410	15 45.72
	11	22 11 56.4	−19.31	5 9.94	0.345	15 45.81
	12	22 4 1.4	20.26	5 18.02	0.328	15 45.84
	13	21 55 43.6	21.21	5 25.67	0.310	15 45.88
August	14	14 33 29.8	−45.94	4 39.58	0.448	15 49.33
	15	14 15 0.2	46.52	4 28.57	0.470	15 49.50
	16	13 56 16.9	47.09	4 17.04	0.491	15 49.67
				Added to Mean Time		
September	16	2 52 22.6	−57.86	4 55.88	0.881	15 56.58
	17	2 29 12.2	58.00	5 17.06	0.882	15 56.84
	18	2 5 58.7	58.12	5 38.24	0.882	15 57.10
October	3	S 3 44 18.1	−58.10	10 44.13	0.785	16 1.22
	4	4 7 31.1	57.98	11 2.83	0.772	16 1.50
	5	4 30 41.2	57.85	11 21.20	0.757	16 1.77
	9	6 2 46.0	−57.20	12 30.82	0.690	16 2.86
	10	6 25 36.5	57.00	12 47.16	0.671	16 3.13
	11	6 48 22.0	56.78	13 3.03	0.651	16 3.40
	12	7 11 2.1	56.55	13 18.41	0.630	16 3.67

NOTE.—The sign − prefixed to the hourly change of declination indicates that north declinations are decreasing; south declinations increasing.

MARCQ ST. HILAIRE'S METHOD

(PART 2)

FINAL POSITION BY COMPUTATION

CALCULATING THE INTERSECTION POINT OF POSITION LINES

1. Plotting Versus Calculating the Final Fix.—So far, the intersection of the position lines established by St. Hilaire's method has been found by plotting. This is the most logical method of finding the final fix because the position lines, obtained by whatever method of computation, are intended to be plotted on the chart. Some authorities on navigation and men of high professional standing, however, claim that the point of intersection of two position lines should be calculated as well as plotted; in other words, they maintain that a navigator ought to know how to plot and how to compute his final fix.

2. Several methods of calculating the point of intersection have been proposed and all are based on the solution by trigonometric formulas of two or more triangles formed by the intercepts, the azimuths, and the position lines. These methods are necessarily more or less complicated even though tables have been constructed to facilitate calculations and simplify the work.

3. Formulas for Calculating the Point of Intersection.—One of the simplest, and perhaps the most convenient, methods of calculating the point of intersection of

position lines found by the St. Hilaire method is to determine the difference of latitude and the difference of longitude between the assumed, or dead-reckoning, position and the final fix. Thus, in Fig. 1, if the angles a_1 and a_2 represent the azimuths and h_1 and h_2 the corresponding intercepts, the point of intersection Z of the two lines of position $E Z$ and $C Z$ is found by determining BD, the difference of latitude, and $D Z$, the departure. To find $B D$ and $D Z$ from the known quantities a_1, a_2 and h_1, h_2, it is convenient to make use of an auxiliary triangle $R Z F$ formed by extending the position line $C Z$ to the meridian $B F$. It will be noticed that if, in this auxiliary triangle, a perpendicular is drawn from Z toward the meridian, angle $R Z D = a_2$ and angle $D Z F = a_1$, from which follows that the sum of these angles or $R Z F$ is equal to the angle A, or the sum of azimuths.

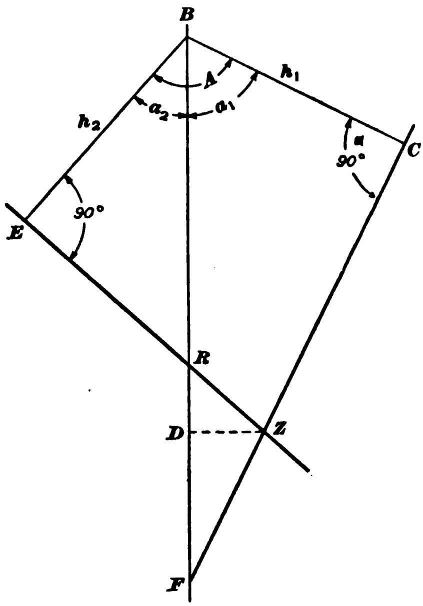


FIG. 1

4. Derivation of Formulas.—The procedure of finding the difference of latitude and departure may now be accomplished as follows:

In the right triangle $B C F$, Fig. 1, $B F = h_1 \sec a_1$.

In the right triangle $B E R$, $B R = h_2 \sec a_2$. Hence,

$$F R = B F - B R = h_1 \sec a_1 - h_2 \sec a_2$$

In the triangle $R Z F$,

$$R Z : F R = \sin R F Z : \sin F Z R$$

Now, the angle $R F Z = (90° - a_1)$ and the angle $F Z R = (a_2 + a_1) = A$. Therefore,

$$R\,Z : F\,R = \sin\,(90^\circ - a_1) : \sin A;$$

whence,

$$R\,Z = \frac{F\,R \sin\,(90^\circ - a_1)}{\sin A} = \frac{F\,R \cos a_1}{\sin A}$$

Substituting in this equation the value of $F\,R$ previously obtained,

$$R\,Z = \frac{(h_1 \sec a_1 - h_2 \sec a_2) \cos a_1}{\sin A}$$

But, $\sec a_1 \times \cos a_1 = 1$; hence,

$$R\,Z = \frac{h_1 - h_2 \sec a_2 \cos a_1}{\sin A}$$

To find the departure $D\,Z$, a perpendicular is dropped from Z toward $R\,F$. In the right triangle $R\,D\,Z$,

$$D\,Z = R\,Z \cos a_2$$

Substituting in this equation the value of $R\,Z$ found above,

$$D\,Z = \frac{\cos a_2 \,(h_1 - h_2 \sec a_2 \cos a_1)}{\sin A}$$

But, $\cos a_2 \times \sec a_2 = 1$; hence,

$$D\,Z = \frac{h_1 \cos a_2 - h_2 \cos a_1}{\sin A};$$

whence, $D\,Z = \operatorname{cosec} A\,(h_1 \cos a_2 - h_2 \cos a_1)$

To find the difference of latitude $B\,D$, Fig. 1, in the right triangles $B\,E\,R$ and $R\,D\,Z$,

$$\begin{array}{c} B\,R = h_2 \sec a_2 \\ \underline{R\,D = R\,Z \sin a_2} \\ B\,R + R\,D = h_2 \sec a_2 + R\,Z \sin a_2 \end{array};$$

or, $B\,D = h_2 \sec a_2 + R\,Z \sin a_2$

Substituting the value of $R\,Z$ previously found,

$$B\,D = h_2 \sec a_2 + \frac{(h_1 - h_2 \sec a_2 \cos a_1) \sin a_2}{\sin A}$$

Multiplying, the equation becomes

$$B\,D = h_2 \sec a_2 + \frac{h_1 \sin a_2 - h_2 \tan a_2 \cos a_1}{\sin A}$$

Transposing,

$$B\,D = h_2 \sec a_2 - \frac{h_2 \tan a_2 \cos a_1}{\sin A} + \frac{h_1 \sin a_2}{\sin A}$$

Now, $\sec a_2 = \frac{1}{\cos a_2}$; hence,

$$B\,D = \frac{h_2}{\cos a_2} - \frac{h_2 \tan a_2 \cos a_1}{\sin A} + \frac{h_1 \sin a_2}{\sin A}$$

Since $\tan a_2 = \frac{\sin a_2}{\cos a_2}$, by substituting this value and factoring,

$$B\,D = h_2 \left(\frac{1}{\cos a_2} - \frac{\sin a_2 \cos a_1}{\cos a_2 \sin A}\right) + \frac{h_1 \sin a_2}{\sin A}$$

Placing the terms within the parenthesis under a common denominator, the equation becomes

$$B\,D = h_2 \frac{\sin A - \sin a_2 \cos a_1}{\cos a_2 \sin A} + \frac{h_1 \sin a_2}{\sin A}$$

But the angle $A = (a_1 + a_2)$; hence,

$$B\,D = h_2 \frac{\sin (a_1 + a_2) - \sin a_2 \cos a_1}{\cos a_2 \sin A} + \frac{h_1 \sin a_2}{\sin A}$$

Again, $\sin (a_1 + a_2) = \sin a_1 \cos a_2 + \cos a_1 \sin a_2$; hence,

$$B\,D = h_2 \frac{\sin a_1 \cos a_2 + \sin a_2 \cos a_1 - \sin a_2 \cos a_1}{\cos a_2 \sin A} + \frac{h_1 \sin a_2}{\sin A}$$

Canceling, the equation becomes

$$B\,D = \frac{h_2 \sin a_1}{\sin A} + \frac{h_1 \sin a_2}{\sin A};$$

whence, $B\,D = \operatorname{cosec} A\ (h_1 \sin a_2 + h_2 \sin a_1)$

5. The formulas found may now be used in calculating the difference of latitude and departure of the point of intersection of any two lines of position computed by the St. Hilaire method. Assuming that a_1 and h_1 represent, respectively, the

first azimuth and intercept, a_2 and h_2 the second azimuth and intercept, as in the foregoing demonstration, the formulas are:

$$\text{Dep.} = \operatorname{cosec} A \ (h_1 \cos a_2 - h_2 \cos a_1)$$
$$\text{D. Lat.} = \operatorname{cosec} A \ (h_1 \sin a_2 + h_2 \sin a_1)$$

While the formulas appear easy of manipulation, certain rules must be followed to meet and comply with the terms involved. Thus, by examining the two formulas it will be noticed that each intercept is multiplied by the sine or cosine of the opposite azimuth.

6. To meet this condition, it is necessary to exchange the intercepts before multiplying, considering h_1 with a_2 and h_2 with a_1.

By the use of Table I, which gives the product of cosecants of angles from 20° to 90° and for intercepts from 1 to 18 miles, and the Traverse Tables, the actual numerical values of difference of latitude and departure are determined. But in order that these values may be correctly named, it is necessary to swing the azimuths to the adjacent quadrants. The transfer of the azimuths and the interchanging of the intercepts may be performed as one operation, care being taken when transferring each of the azimuths to refer its numerical value to the north or south point. Transfer the azimuths in opposite directions and the nearest way.

7. Both Intercepts Positive But in Different Quadrants.—Suppose the position, by dead reckoning, is latitude 50° 14′ N and longitude 27° 19′ W. The azimuth and intercept at first observation are, respectively, S 30° E and 9 miles (+). At the second observation, the azimuth is S 42° W and the intercept 7 miles (+)* Find the latitude and longitude of X, the point of intersection.

First the azimuths are transferred to the adjacent quadrants, retaining their values in arc. But care must be taken to transfer them in opposite directions and the nearest way, as indicated by the arrows in Fig. 2. In this case, the first azimuth

* Intercepts are marked (+) or (−) indicating *toward* or *from* the observed body.

is S 30° E and when transferred to the adjacent quadrant it becomes S 30° W. The second azimuth is S 42° W and when transferred becomes S 42° E, but the intercepts remain the same. Thus,

For intercept 9 miles the azimuth is S 42° E
For intercept 7 miles the azimuth is S 30° W

The angle contained between the lines representing the azimuth is next determined. If this angle, which is designated by

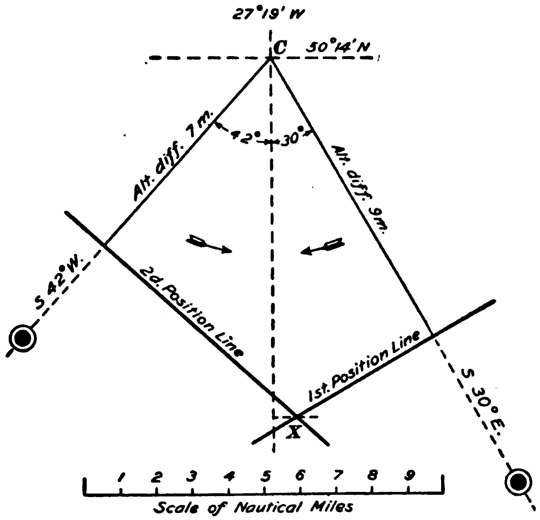


FIG. 2

the letter A, should exceed 90° its supplement is used. In this case

$$A = 42° + 30° = 72°$$

Each intercept is now multiplied by the cosecant for the angle A. To facilitate this multiplication use Table I, which is entered with the intercept at the top and the angle A in the vertical column to the left. Thus,

For intercept 9 and 72° the result is 9.5
For intercept 7 and 72° the result is 7.4

These factors are now entered in a traverse as distances together with azimuths as courses. Thus,

TRAVERSE

Azimuths	Factors	D. Lat.		Dep.	
		N	S	E	W
S 42° E	9.5	——	6.4	7.1	——
S 30° W	7.4	——	3.7	——	6.4

D. Lat. = 10.1′ S Dep. = .7′ E

8. When picking out the difference of latitude and the departure from ordinary traverse tables, reverse these data by entering the difference of latitude in the departure column and the departure in the difference of latitude column; or, read the tables from the bottom when azimuths are less than 45° and from the top when the azimuths are greater than 45°. This is necessary on account of the change made in names of original azimuths.

9. The departure, .7′ E, is now converted into the corresponding difference of longitude by Traverse Tables, by Table I, or by the formula D. Long. = Dep. × sec. Lat. Entering the Traverse Tables with the latitude 50° as course and the departure .7 in a latitude column, the corresponding difference of longitude, in this case 1.1′ E, is found in the distance column. The same result would be had by entering Table I with 50° in vertical column marked Lat. and the departure at the top of the table. Opposite 50° and below .7 is found the difference of longitude, 1.09′, or, practically, 1.1′.

10. The difference of latitude and difference of longitude are then applied to the dead-reckoning position in the usual way. The result is the required latitude and longitude of the point of intersection X, Fig. 2, between the two position lines. Thus,

D. R. Lat. = 50° 14′ N	D. R. Long. = 27° 19′ W
D. Lat. = 10.1′ S	D. Long. = 1.1′ E
Lat. of X = 50° 3.9′ N	Long. of X = 27° 17.9′ W

TABLE I

FACTORS TO BE USED IN FINDING THE INTERSECTION OF ST. HILAIRE'S LINES

Azimuth Difference Degrees	Intercepts; Also Departure																		Latitude Degrees
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
90	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	0
86	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	4
84	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	6
82	1.0	2.0	3.0	4.0	5.0	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.2	17.2	18.2	8
80	1.0	2.0	3.0	4.1	5.1	6.1	7.1	8.1	9.1	10.2	11.2	12.2	13.2	14.2	15.2	16.2	17.3	18.3	10
78	1.0	2.0	3.1	4.1	5.1	6.1	7.2	8.2	9.2	10.2	11.2	12.3	13.3	14.3	15.3	16.4	17.4	18.4	12
76	1.0	2.1	3.1	4.1	5.2	6.2	7.2	8.2	9.3	10.3	11.3	12.4	13.4	14.4	15.5	16.5	17.5	18.6	14
74	1.0	2.1	3.1	4.2	5.2	6.2	7.3	8.3	9.4	10.4	11.4	12.5	13.5	14.6	15.6	16.6	17.7	18.7	16
72	1.1	2.1	3.2	4.2	5.3	6.3	7.4	8.4	9.5	10.5	11.6	12.6	13.7	14.7	15.8	16.8	17.9	18.9	18
70	1.1	2.1	3.2	4.3	5.3	6.4	7.4	8.5	9.6	10.6	11.7	12.8	13.8	14.9	16.0	17.0	18.1	19.2	20
69	1.1	2.1	3.2	4.3	5.4	6.4	7.5	8.6	9.6	10.7	11.8	12.9	13.9	15.0	16.1	17.1	18.2	19.3	21
68	1.1	2.2	3.2	4.3	5.4	6.5	7.5	8.6	9.7	10.8	11.9	12.9	14.0	15.1	16.2	17.3	18.3	19.4	22
67	1.1	2.2	3.3	4.3	5.4	6.5	7.6	8.7	9.8	10.9	12.0	13.0	14.1	15.2	16.3	17.4	18.5	19.6	23
66	1.1	2.2	3.3	4.4	5.5	6.6	7.7	8.8	9.9	10.9	12.0	13.1	14.2	15.3	16.4	17.5	18.6	19.7	24
65	1.1	2.2	3.3	4.4	5.5	6.6	7.7	8.8	9.9	11.0	12.1	13.2	14.3	15.4	16.6	17.7	18.8	19.9	25
64	1.1	2.2	3.3	4.5	5.6	6.7	7.8	8.9	10.0	11.1	12.2	13.4	14.5	15.6	16.7	17.8	18.9	20.0	26
63	1.1	2.2	3.4	4.5	5.6	6.7	7.9	9.0	10.1	11.2	12.3	13.5	14.6	15.7	16.8	18.0	19.1	20.2	27
62	1.1	2.3	3.4	4.5	5.7	6.8	7.9	9.1	10.2	11.3	12.5	13.6	14.7	15.9	17.0	18.1	19.3	20.4	28
61	1.1	2.3	3.4	4.6	5.7	6.9	8.0	9.1	10.3	11.4	12.6	13.7	14.9	16.0	17.2	18.3	19.4	20.6	29
60	1.2	2.3	3.5	4.6	5.8	6.9	8.1	9.2	10.4	11.5	12.7	13.9	15.0	16.2	17.3	18.5	19.6	20.8	30
59	1.2	2.3	3.5	4.7	5.8	7.0	8.2	9.3	10.5	11.7	12.8	14.0	15.2	16.3	17.5	18.7	19.8	21.0	31
58	1.2	2.4	3.5	4.7	5.9	7.1	8.3	9.4	10.6	11.8	13.0	14.2	15.3	16.5	17.7	18.9	20.0	21.2	32
57	1.2	2.4	3.6	4.8	6.0	7.2	8.3	9.5	10.7	11.9	13.1	14.3	15.5	16.7	17.9	19.1	20.3	21.5	33
56	1.2	2.4	3.6	4.8	6.0	7.2	8.4	9.6	10.9	12.1	13.3	14.5	15.7	16.9	18.1	19.3	20.5	21.7	34
55	1.2	2.4	3.7	4.9	6.1	7.3	8.5	9.8	11.0	12.2	13.4	14.6	15.9	17.1	18.3	19.5	20.8	22.0	35
54	1.2	2.5	3.7	4.9	6.2	7.4	8.7	9.9	11.1	12.4	13.6	14.8	16.1	17.3	18.5	19.8	21.0	22.2	36
53	1.3	2.5	3.8	5.0	6.3	7.5	8.8	10.0	11.3	12.5	13.8	15.0	16.3	17.5	18.8	20.0	21.3	22.5	37

52	1.3	2.5	3.8	5.1	6.3	7.6	8.9	10.2	11.4	12.7	14.0	15.2	16.5	17.8	19.0	20.3	21.6	22.8	38
51	1.3	2.6	3.9	5.1	6.4	7.7	9.0	10.3	11.6	12.9	14.2	15.4	16.7	18.0	19.3	20.6	21.9	23.2	39
50	1.3	2.6	3.9	5.2	6.5	7.8	9.1	10.4	11.7	13.1	14.4	15.7	17.0	18.3	19.6	20.9	22.2	23.5	40
49	1.3	2.7	4.0	5.3	6.6	8.0	9.3	10.6	11.9	13.3	14.6	15.9	17.2	18.6	19.9	21.2	22.5	23.9	41
48	1.3	2.7	4.0	5.4	6.7	8.1	9.4	10.8	12.1	13.5	14.8	16.1	17.5	18.8	20.2	21.5	22.9	24.2	42
47	1.4	2.7	4.1	5.5	6.8	8.2	9.6	10.9	12.3	13.7	15.0	16.4	17.8	19.1	20.5	21.9	23.2	24.6	43
46	1.4	2.8	4.2	5.6	7.0	8.3	9.7	11.1	12.5	13.9	15.3	16.7	18.1	19.5	20.9	22.2	23.6	25.0	44
45	1.4	2.8	4.2	5.7	7.1	8.5	9.9	11.3	12.7	14.1	15.6	17.0	18.4	19.8	21.2	22.6	24.0	25.5	45
44	1.4	2.9	4.3	5.8	7.2	8.6	10.1	11.5	13.0	14.4	15.8	17.3	18.7	20.2	21.6	23.0	24.5	25.9	46
43	1.5	2.9	4.4	5.9	7.3	8.8	10.3	11.7	13.2	14.7	16.1	17.6	19.1	20.5	22.0	23.5	24.9	26.4	47
42	1.5	3.0	4.5	6.0	7.5	9.0	10.5	12.0	13.5	14.9	16.4	17.9	19.4	20.9	22.4	23.9	25.4	26.9	48
41	1.5	3.0	4.6	6.1	7.6	9.1	10.7	12.2	13.7	15.2	16.8	18.3	19.8	21.3	22.9	24.4	25.9	27.4	49
40	1.6	3.1	4.7	6.2	7.8	9.3	10.9	12.4	14.0	15.6	17.1	18.7	20.2	21.8	23.3	24.9	26.4	28.0	50
39	1.6	3.2	4.8	6.4	7.9	9.5	11.1	12.7	14.3	15.9	17.5	19.1	20.7	22.2	23.8	25.4	27.0	28.6	51
38	1.6	3.2	4.9	6.5	8.1	9.7	11.4	13.0	14.6	16.2	17.9	19.5	21.1	22.7	24.4	26.0	27.6	29.2	52
37	1.7	3.3	5.0	6.6	8.3	10.0	11.6	13.3	15.0	16.6	18.3	19.9	21.6	23.3	24.9	26.6	28.2	29.9	53
36	1.7	3.4	5.1	6.8	8.5	10.2	11.9	13.6	15.3	17.0	18.7	20.4	22.1	23.8	25.5	27.2	28.9	30.6	54
35	1.7	3.5	5.2	7.0	8.7	10.5	12.2	13.9	15.7	17.4	19.2	20.9	22.7	24.4	26.2	27.9	29.6	31.4	55
34	1.8	3.6	5.4	7.2	8.9	10.7	12.5	14.3	16.1	17.9	19.7	21.5	23.2	25.0	26.8	28.6	30.4	32.2	56
33	1.8	3.7	5.5	7.3	9.2	11.0	12.9	14.7	16.5	18.4	20.2	22.0	23.9	25.7	27.5	29.4	31.2	33.0	57
32	1.9	3.8	5.7	7.5	9.4	11.3	13.2	15.1	17.0	18.9	20.8	22.6	24.5	26.4	28.3	30.2	32.1	34.0	58
31	1.9	3.9	5.8	7.8	9.7	11.6	13.6	15.5	17.5	19.4	21.4	23.3	25.2	27.2	29.1	31.1	33.0	34.9	59
30	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0	24.0	26.0	28.0	30.0	32.0	34.0	36.0	60
29	2.1	4.1	6.2	8.3	10.3	12.4	14.4	16.5	18.6	20.6	22.7	24.8	26.8	28.9	30.9	33.0	35.1	37.1	61
28	2.1	4.3	6.4	8.5	10.7	12.8	14.9	17.0	19.2	21.3	23.4	25.6	27.7	29.8	32.0	34.1	36.2	38.3	62
27	2.2	4.4	6.6	8.8	11.0	13.2	15.4	17.6	19.8	22.0	24.2	26.4	28.6	30.8	33.0	35.2	37.4	39.6	63
26	2.3	4.6	6.8	9.1	11.4	13.7	16.0	18.2	20.5	22.8	25.1	27.4	29.7	31.9	34.2	36.5	38.8	41.1	64
25	2.4	4.7	7.1	9.5	11.8	14.2	16.6	18.9	21.3	23.7	26.0	28.4	30.8	33.1	35.5	37.9	40.2	42.6	65
24	2.5	4.9	7.4	9.8	12.3	14.8	17.2	19.7	22.1	24.6	27.0	29.5	32.0	34.4	36.9	39.3	41.8	44.3	66
23	2.6	5.1	7.7	10.2	12.8	15.4	17.9	20.5	23.0	25.6	28.2	30.7	33.3	35.8	38.4	40.9	43.5	46.1	67
22	2.7	5.3	8.0	10.7	13.3	16.0	18.7	21.4	24.0	26.7	29.4	32.0	34.7	37.4	40.0	42.7	45.4	48.1	68
21	2.8	5.6	8.4	11.2	14.0	16.7	19.5	22.3	25.1	27.9	30.7	33.5	36.3	39.1	41.9	44.6	47.4	50.2	69
20	2.9	5.8	8.8	11.7	14.6	17.5	20.5	23.4	26.3	29.2	32.2	35.1	38.0	40.9	43.9	46.8	49.7	52.6	70

11. Intercepts Positive and in Same Quadrant. The position, by dead reckoning, is latitude 56° 12′ N and longitude 19° 26′ E. The azimuth and intercept at first observation are S 82° E, 6.5 miles (+). At second observation, the azimuth is S 40° E and the intercept 8 miles (+). Find the latitude and the longitude of the true position.

As before, each azimuth is transferred to the adjacent quadrant. In this case, Fig. 3, the azimuths are in the same, or

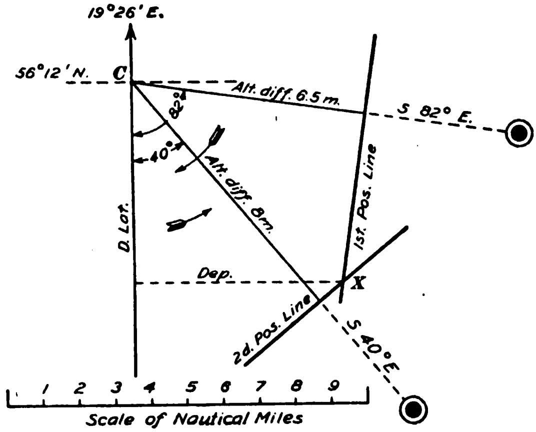


FIG. 3

the S E quadrant. The transfer, therefore, is effected as follows: The S 40° E azimuth is changed to the N E quadrant, and the S 82° E azimuth to the S W quadrant. Hence,

For intercept 6.5 miles the azimuth is N 40° E
For intercept 8 miles the azimuth is S 82° W

The angle subtended between the azimuth lines in this case is equal to the difference in the two azimuths; or,

$$A = 82° - 40° = 42°$$

Table I is then entered as before and the corresponding factors picked out; thus,

For intercept 6.5 and 42° the factor is 9.8
For intercept 8 and 42° the factor is 12

Forming a traverse and entering the factors as distances and the converted azimuths as courses, the result is as follows:

TRAVERSE

Azimuths	Factors	D. Lat.		Dep.	
		N	S	E	W
N 40° E	9.8	6.3	——	7.5	——
S 82° W	12	——	11.9	——	1.7

D. Lat. = 5.6′ S Dep. = 5.8′ E

The latitude in this case being 56°, the difference in longitude corresponding to this latitude and departure 5.8, as found in the Traverse Tables, or Table I, is 10.4′ E. Hence,

D. R. Lat. =	56° 12′ N	D. R. Long. =	19° 26′ E
D. Lat. =	5.6′ S	D. Long. =	10.4′ E
Lat. X =	56° 6.4′ N	Long. X =	19° 36.4′ E

12. One Intercept Positive and One Negative, But in Same Quadrant.—Position, by dead reckoning, is latitude 16° 25′ S, longitude 38° 1′ W. Azimuth and intercept at first observation is S 12° W, 10.3 miles (−); at second observation, S 68° W, 5.5 miles (+). Find, by calculation, the latitude and longitude of the true position.

The azimuths and intercepts given in this example are shown in Fig. 4. The altitude difference at the first sight is negative, or *from* the observed body. It is, therefore, laid off in the opposite direction, or N 12° E, as shown, and treated as a N E azimuth. As before, each azimuth is transferred to the nearest adjacent quadrant. Thus,

For intercept 5.5 miles the azimuth is N 12° W
For intercept 10.3 miles the azimuth is N 68° W

The angle subtended by the azimuth lines is equal to the difference between the given azimuths; or,

$$A = 68° - 12° = 56°$$

Entering Table I with this angle and these intercepts:

For intercept 5.5 and 56° the result is 6.6
For intercept 10.3 and 56° the result is 12.5

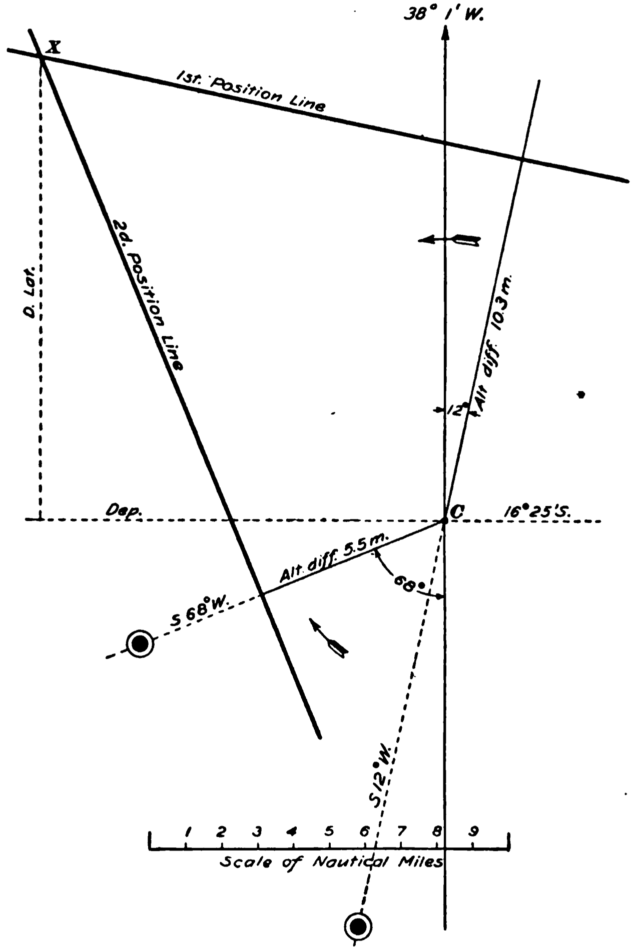


FIG. 4

The traverse formed by inserting these factors and converted azimuths is:

TRAVERSE

Azimuths	Factors	D. Lat.		Dep.	
		N	S	E	W
N 12° W	6.6	1.4	—	—	6.5
N 68° W	12.5	11.6	—	—	4.7
		D. Lat. = 13.0′ N		Dep. = 11.2′ W	

The difference of longitude corresponding to the found departure and the dead-reckoning latitude is 11.7′. Hence,

D. R. Lat. = 16° 25′ S	D. R. Long. = 38° 1′ W
D. Lat. = 13.0′ N	D. Long. = 11.7′ W
Lat. X = 16° 12.0′ S	Long. X = 38° 12.7′ W

13. One Intercept Positive and One Negative, But in Different Quadrants.—The latitude and longitude by dead reckoning, are 52° 10′ S and 60° 17′ W. First observation gives the azimuth as N 5° W and the intercept 12.8 miles (+). Second observation, the azimuth is S 87° E and the intercept 3.5 miles (−). Find the true position.

In this case, one of the intercepts is negative, or *away* from the observed body, and hence it is reversed from S 87° E to N 87° W, 3.5 miles. Transferring the azimuth to adjacent quadrants, as shown by the arrows in Fig. 5, they become:

For intercept 3.5 miles the azimuth is S 5° W
For intercept 12.8 miles the azimuth is N 87° E

The angle subtended by the azimuth lines in this case exceeds 90° and its supplement is therefore taken; or,

$$A = 180° - (5° + 90° + 3°) = 82°$$

Table I is then entered and the factors corresponding to this angle and the intercepts are picked out; thus,

For intercept 3.5 and 82° the factor is 3.5
For intercept 12.8 and 82° the factor is 12.9

Entering these in a traverse with the converted azimuth, the resulting difference of latitude and departure are as follows:

Traverse

Azimuths	Factors	D. Lat.		Dep.	
		N	S	E	W
S 5° W	3.5	——	0.3	——	3.5
N 87° E	12.9	12.9	——	0.7	——

D. Lat. = 12.6′ N Dep. = 2.8′ W

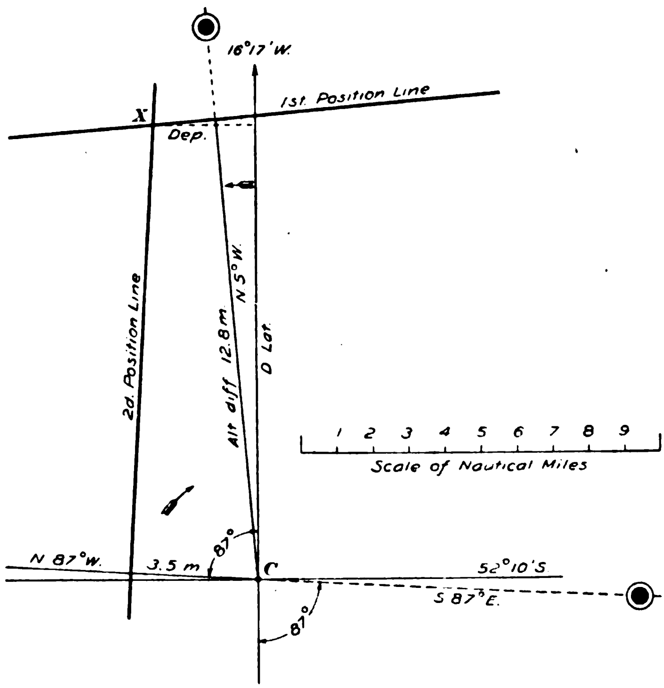


Fig. 5

For latitude, by dead reckoning, 52° and the departure 2.8′, the corresponding difference of longitude is 4.5′ W. The true position is therefore:

D. R. Lat. = 52° 10′ S	D. R. Long. = 60° 17′ W
D. Lat. = 12.6′ N	D. Long. = 4.5′ W
Lat. X = 51° 57.4′ S	Long. X = 60° 21.5′ W

14. Both Intercepts Negative.—Position, by dead reckoning, is: latitude 63° 14′ N and longitude 23° 11′ W. Azimuth and intercept at first observation are S 32° W and 6 miles (−); at second observation, S 65° W and 11.7 miles (−). Find the latitude and the longitude at the intersection of the two lines of position.

In this case, both intercepts are negative and therefore when reversed the azimuths become, respectively, N 32° E and

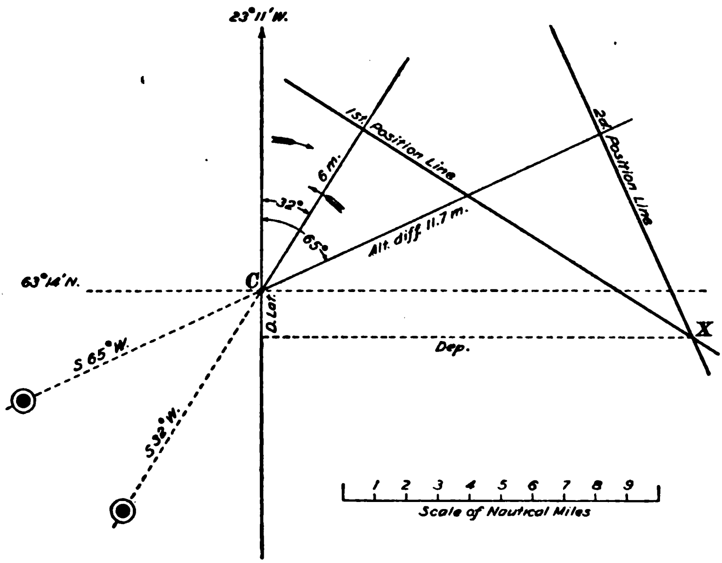


FIG. 6

N 65° E, as shown in Fig. 6. Transferred to adjacent quadrants (as shown by the arrows), these azimuths with intercepts will be as follows:

For intercept 11.7 miles the azimuth is S 32° E
For intercept 6 miles the azimuth is N 65° W

The angle $A = 65° - 32° = 33°$. From Table I the factors corresponding to A and intercepts are obtained; thus,

For intercept 11.7 and 33° the factor is 21.5
For intercept 6 and 33° the factor is 11.0

Forming the usual traverse, the corresponding difference of latitude and departure are obtained; thus,

TRAVERSE

Azimuths	Factors	D. Lat.		Dep.	
		N	S	E	W
S 32° E	21.5	——	11.4	18.2	——
N 65° W	11.0	10.0	——	——	4.6

D. Lat. = 1.4′ S Dep. = 13.6′ E

For latitude 63° and departure 13.6, the corresponding difference of longitude is 30′ E. Hence,

D. R. Lat. = 63° 14′ N	D. R. Long. = 23° 11′ W
D. Lat. = 1.4′ S	D. Long. = 30′ E
Lat. X = 63° 12.6′ N	Long. X = 22° 41′ W

15. One Intercept Along Cardinal Point.—Suppose the dead-reckoning position is latitude 39° N and 42° 16′ W. The azimuth and intercept at first observation are South, 13 miles (+); at second sight, N 48° E, 10 miles (+). Find the true position.

As before, the azimuths are transferred to the adjacent quadrants. In this case, Fig. 7, the south azimuth is transferred to east while the northeast azimuth is changed to the southeast quadrant; thus,

For intercept 13 miles the azimuth is S 48° E
For intercept 10 miles the azimuth is S 90° E

The angle $A = 180° - (90° + 42°) = 48°$. From Table I, the factors are obtained; thus,

For intercept 13 and 48° the factor is 17.5
For intercept 10 and 48° the factor is 13.5

Entering them in a traverse as before, the corresponding difference of latitude and departure are obtained; thus,

TRAVERSE

Azimuths	Factors	D. Lat.		Dep.	
		N	S	E	W
S 48° E	17.5	——	13.0	11.7	——
East	13.5	——	——	13.5	——

D. Lat. = 13.0′ S Dep. = 25.2′ E

For latitude 39° and a departure 25.2, the corresponding difference in longitude is 32.4′ E. Hence,

D. R. Lat. = 39° 0′ N	D. R. Long. = 42° 16′ W
D. Lat. = 13′ S	D. Long. = 32.4′ E
Lat. X = 38° 47′ N	Long. X = 41° 43.6′ W

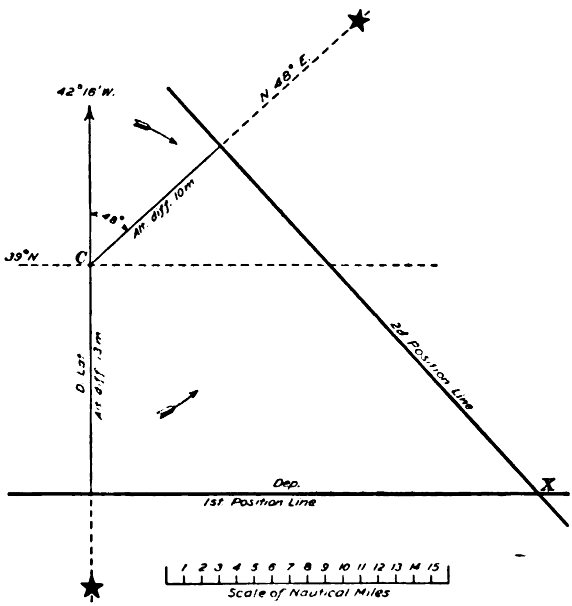


FIG. 7

EXAMPLES FOR PRACTICE

1. The assumed position is latitude 55° 10′ N, longitude 5° 52′ E. The first azimuth is S 54° E; intercept, 1.6 miles (−). The second azimuth is S 16° E; intercept, 7.5 miles (+). Find the point of intersection.

Ans. { Lat. = 54° 59.4′ N; Long. = 5° 35′ E }

2. The dead-reckoning position is latitude 16° 25′ S, longitude 42° 30′ W. The first azimuth and intercept are S 12° W and 10.3 miles (−); the second azimuth and intercept are S 68° W and 5.5 miles (+). Find the point of intersection.

Ans. { Lat. = 16° 12′ S; Long. = 42° 41.5′ W }

3. The assumed position is latitude 48° 9.5′ N, longitude 22° 56′ W. The first azimuth and intercept are N 76° 30′ E and 13 miles (+); the second azimuth and intercept are S 34° E and 2 miles (−). Find the point of intersection.

Ans. { Lat. = 48° 19.1′ N; Long. = 22° 40′ W }

4. The dead-reckoning position is latitude 14° 56′ S, longitude 38° 28′ W. The first azimuth and intercept are S 68° E and 12.4 miles (+); the second azimuth and intercept are N 43° E and 12.2 miles (+). Find latitude and longitude of the point of intersection.

Ans. { Lat. = 14° 52.9′ S; Long. = 38° 13′ W }

5. The position, by dead reckoning, is latitude 39° 6′ S, longitude 35° 44.5′ E. The first azimuth and intercept are N 74° W and 28.5 miles (−); the second azimuth and intercept are N 44° 30′ E and 8 miles (−). Find latitude and longitude of the point of intersection.

Ans. { Lat. = 39° 37.4′ S; Long. = 36° 11′ E }

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16. Use of Diagrams.—The foregoing examples should give a clear idea how to find by calculation the intersection point of two lines established by the St. Hilaire method. After some practice it is possible to perform these calculations without the aid of a figure; but, until such a proficiency is attained, it is well to use a rough diagram on which azimuths and intercepts are approximately plotted. Such a diagram, no matter how roughly drawn, will be of great help in avoiding mistakes when the transfer of azimuths is made.

17. Limitations of Table I.—It will be noticed that Table I is limited to a distance of 18 miles for intercepts and

departures. If it is desired to use the table for greater distances the excess of 18 is entered and the corresponding numbers added to those for 18 miles. Thus, if the angle A is 46° and the intercept 26 miles, Table I is entered with 46° and 18; the resulting number is 25.0. Then the number corresponding to 46° and 8 miles, which is 11.1, is taken out. This added to the former will give 25.0+11.1=36.1, which is the factor corresponding to 46° and an intercept of 26 miles. The same procedure is followed when picking out the difference of longitude corresponding to a departure exceeding 18 miles. A case where one of the intercepts and the departure exceed the limits of Table I is shown in the following example:

EXAMPLE.—On August 18, 1914, at about 4:30 A. M., simultaneous sights were taken of the stars Fomalhaut and Rigel. The observed altitude of the former was 12° 56′ 20″ west of the meridian; of the latter 33° 37′ 20″ east of the meridian. Height of eye=21 feet. Index error =+3′ 40″. Chronometer at instant of observations indicated $1^h\ 33^m\ 27^s$, its error on Greenwich mean time being $6^m\ 22^s$ fast. By dead reckoning, the position of the ship was estimated to be latitude 29° 40′ N and longitude 134° W. The azimuth of Fomalhaut was S 44° W and that of Rigel S 55° E. Find lines of position, by St. Hilaire's method, and, by calculation, the true position of the ship.

SOLUTION.—Work out both sights in the usual way and find the intercept, or altitude difference, in each case; then use method described to find by calculation the latitude and longitude of the point of intersection of the two lines of position.

Computation for Fomalhaut

Chron. =	$1^h\ 33^m\ 27^s$	Sid. T. G. M. N. =	$9^h\ 44^m\ 1.61^s$
Error (fast) =	$-\ \ 6^m\ 22^s$	Corr. for $1^h\ 27^m$ =	$+\ \ 14.3^s$
G. M. T., Aug. 18 =	$1^h\ 27^m\ 5^s$	R. A. M. S. =	$9^h\ 44^m\ 15.91^s$
R. A. M. S. =	$9^h\ 44^m\ 16^s$		
G. Sid. T., Aug. 18 =	$11^h\ 11^m\ 21^s$	✱ Decl. =	S 30° 4′ 42″
Long. 134° W =	$8^h\ 56^m\ 0^s$	✱ R. A. =	$22^h\ 52^m\ 54^s$
L. Sid. T., Aug. 18 =	$2^h\ 15^m\ 21^s$	Obs. Alt. =	12° 56′ 20″
Or =	$26^h\ 15^m\ 21^s$	I. E. =	+ 3′ 40″
✱ R. A. =	$22^h\ 52^m\ 54^s$		13° 0′ 0″
✱ H. A. =	$3^h\ 22^m\ 27^s$	Dip =	− 4′ 29″
Or =	50° 36′ 45″		12° 55′ 31″
		Ref. =	− 4′ 4″
		True Alt. =	12° 51′ 27″

cos H. A. 50° 36′ 45″ = 9.80248

sin l 29° 40′ = 9.69456	cos l = 9.93898
sin d 30° 4.7′ = 9.69999 (−)	cos d = 9.93719
log A = 9.39455	log B = 9.67865
A = .24806 (−)	B = .47714
	A = .24806 (−)
	Nat. sin $a = A + B$ = .22908
	Whence, a = 13° 14′ 34″

Obs. Alt. Fomalhaut = 12° 51′ 27″
Cal. Alt. Fomalhaut = 13° 14′ 34″
Intercept, or Alt. Diff. = 23′ 7″
Or = 23 mi. *from* observed body

Computation for Rigel

G. Sid. T., Aug. 18 = 11ʰ 11ᵐ 21ˢ	✱ R. A. = 5ʰ 10ᵐ 25ˢ
Long. 134° W = 8ʰ 56ᵐ 0ˢ	✱ Decl. = S 8° 18′ 1″
L. Sid. T., Aug. 18 = 2ʰ 15ᵐ 21ˢ	Obs. Alt. = 33° 37′ 20″
✱ R. A. = 5ʰ 10ᵐ 25ˢ	I. E. = + 3′ 40″
✱ H. A. = 2ʰ 55ᵐ 4ˢ	33° 41′ 0″
Or = 43° 46′	Dip = − 4′ 29″
	33° 36′ 31″
	Ref. = − 1′ 26″
	True Alt. = 33° 35′ 5″

cos H. A. 43° 46′ = 9.85864

sin l 29° 40′ = 9.69456	cos l = 9.93898
sin d 8° 18′ = 9.15944 (−)	cos d = 9.99543
log A = 8.85400	log B = 9.79305
A = .07145 (−)	B = .62095
	A = .07145 (−)
	Nat. sin $a = A + B$ = .54950
	Whence, a = 33° 20′

Obs. Alt. Rigel = 33° 35′
Cal. Alt. Rigel = 33° 20′
Intercept, or Alt. Diff. = 15 mi. *toward* observed body

18. To find by calculation the final fix of the two lines, draw on a piece of paper a rough sketch representing azimuths and lines of position. This may be done freehand without any attempt at accuracy, something on the order shown in Fig. 8. In this case the intercept from Fomalhaut is negative and the azimuth is therefore reversed from S 44° W to N 44° E. Transferring the azimuths,

For intercept 15 miles the azimuth is S 44° E
For intercept 23 miles the azimuth is N 55° E

The angle subtended by intercepts is equal to the sum of complements of the two azimuths; or,

$$A = 46° + 35° = 79°$$

From Table I are obtained:

For intercept 15 and 79° the factor 15.4
For intercept 23 and 79° the factor 23.6

The factor for 23 miles, which exceeds the limit of the table, is obtained by adding the figures for 18 and 5 miles,

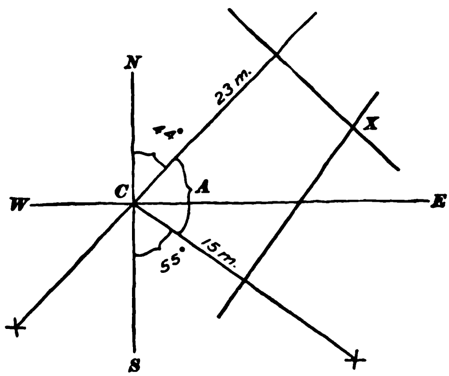

FIG. 8

respectively. The factors are now entered in a traverse and the corresponding difference of latitude and departure are obtained; thus,

TRAVERSE

Azimuths	Factors	D. Lat.		Dep.	
		N	S	E	W
S 44° E	15.4	——	10.7	11.0	——
N 55° E	23.6	19.3	——	13.5	——

D. Lat. = 8.6′ N Dep. = 24.5′ E

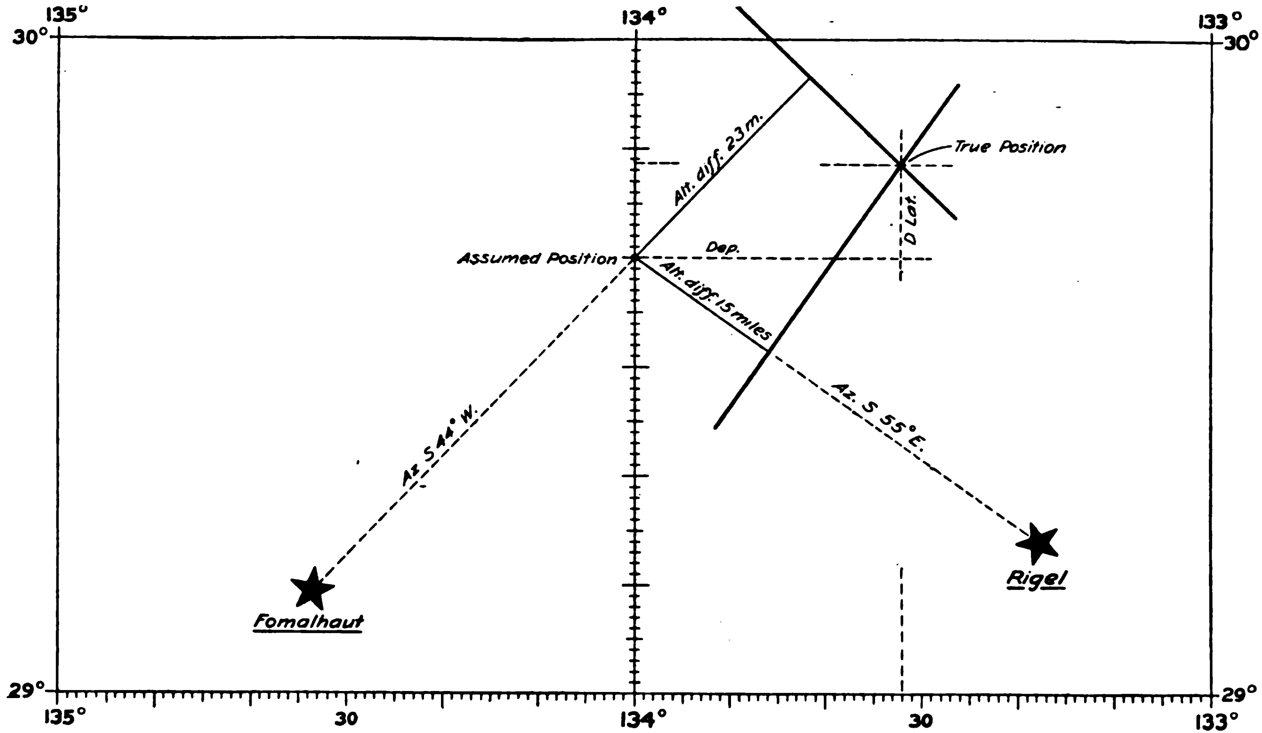
135°
134°
133°
30°
29°
30
Alt. diff. 23 m.
True Position
D Lat.
Dep.
Assumed Position
Alt. diff. 15 miles
Az. S 55° E.
Az. S 44° W.
Rigel
Fomalhaut

FIG. 9

As the departure in this case exceeds the limit of Table I, the corresponding difference of longitude is obtained by entering the table with the dead-reckoning latitude and taking the sum of the values found for 18 and 6.5 miles, respectively; or, D. Long. = 20.6 + 7.5 = 28.1′ E. The final fix by the two position lines is then found in the usual way; thus,

D. R. Lat. =	29° 40′ N	D. R. Long. =	134° 0′ W
D. Lat. =	8.6′ N	D. Long. =	28.1′ E
Lat. in =	29° 48.6′ N	Long. in =	133° 31.9′ W

19. In Fig. 9 are plotted, to scale, the intercepts and position lines worked out in the preceding example. By actual measurements on this chart, it will be seen that the final fix found by calculation agrees exactly with that obtained by plotting.

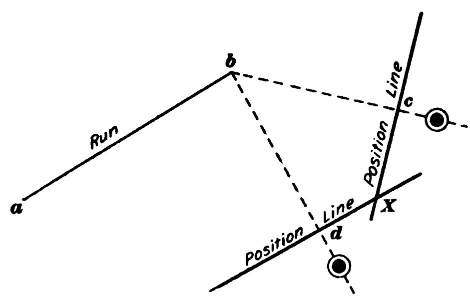

FIG. 10

20. Treatment of Run Between Sights.—In the preceding examples no account is taken of run made between observations. All sights treated are supposed to be simultaneous or taken with an interval at the same locality. In practice, however, the ship is under way and sights taken at the same place are exceptional. It should be noted that run does not affect the method described; it merely changes the position from which the intercepts are laid off. Thus, in Fig. 10, if *a* represents the assumed, or dead-reckoning, position, and *a b* the run made by the ship between sights, the point *b* is used as a base instead of *a* in laying off the intercepts *b c* and *b d*. The latitude and longitude of *b*, the second position, are found in the usual way by applying to position *a* the difference of latitude and departure due to the run between sights.

In the example that follows is shown the method applied to a set of observations taken with run of ship between sights.

EXAMPLE.—On July 6, 1914, when position of ship by dead reckoning was latitude 47° 48′ N and longitude 33° 45′ W, the following sight and data were obtained: Observed altitude ⊖ was 19° 7′ 46″; Greenwich apparent time was 8^h 28^m 51^s A. M.; the corrected declination was 22° 46′ 33″ N; and the azimuth was N 76° 30′ E. After a run N 75° E, 83 miles, a second sight was taken as follows: Observed altitude ⊖, 61° 11′ 55″; Greenwich apparent time, 12^h 59^m 11^s; corrected declination, 22° 45′ 28″ N; and azimuth, S 34° E. Find, by St. Hilaire's method, the two lines of position and determine, by calculation, the latitude and longitude of their point of intersection.

SOLUTION.—Compute the altitude at first sight and find the first intercept; thus,

$$
\begin{array}{rl}
\text{G. App. T., July 6} = & 8^h\ 28^m\ 51^s \\
\text{Long. } (33°\ 45'\ \text{W}) \text{ in time} = & 2^h\ 15^m\ \ 0^s \\
\hline
\text{L. App. T., July 6} = & 6^h\ 13^m\ 51^s \text{ A. M.} \\
\text{Whence, H. A.} = & 5^h\ 46^m\ \ 9^s \\
\text{Or, H. A.} = & 86°\ 32'\ 15''
\end{array}
$$

$$
\begin{array}{rr}
 & \cos \text{H. A. } 86°\ 32'\ 15'' = 8.78100 \\
\sin l\ 47°\ 48'\ 0'' = 9.86970 & \cos l = 9.82719 \\
\sin d\ 22°\ 46'\ 33'' = 9.58786 & \cos d = 9.96474 \\
\log A = 9.45756 & \log B = 8.57293 \\
A = \ .28679 & B = \ .03741 \\
 & A = \ .28679 \\
 & \text{Nat. } \sin a = A + B = \ .32420 \\
 & \text{Whence, } a = 18°\ 55'\ 2''
\end{array}
$$

$$
\begin{array}{rl}
\text{Obs. Alt. } \ominus = & 19°\ \ 7'\ 46'' \\
\text{Cal. Alt. } \ominus = & 18°\ 55'\ \ 2'' \\
\hline
\text{Alt. Diff., or intercept} = & \quad 12'\ 44''\ (+), \text{ or } \textit{toward} \text{ the observed body}
\end{array}
$$

To find the latitude and the longitude at second sight apply course and distance run; thus,

$$
\begin{array}{rl}
\text{D. R. Lat.} = & 47°\ 48'\ \ \text{N} \\
\text{D. Lat.} = & \quad 21.5'\ \text{N} \\
\hline
\text{Lat. in} = & 48°\ \ 9.5'\ \text{N}
\end{array}
\qquad
\begin{array}{rl}
\text{D. R. Long.} = & 33°\ 45'\ \text{W} \\
\text{D. Long.} = & \ \ 2°\ \ 0'\ \text{E} \\
\hline
\text{Long. in} = & 31°\ 45'\ \text{W}
\end{array}
$$

Then calculate the altitude at second sight:

$$
\begin{array}{rl}
\text{G. App. T., July 6} = & 12^h\ 59^m\ 11^s \\
\text{Long. } (31°\ 45'\ \text{W}) \text{ in time} = & \ \ 2^h\ \ 7^m\ \ 0^s \\
\hline
\text{L. App. T., July 6} = & 10^h\ 52^m\ 11^s \text{ A. M.} \\
\text{Whence, H. A.} = & \ \ 1^h\ \ 7^m\ 49^s \\
\text{Or, H. A.} = & 16°\ 57'\ 15''
\end{array}
$$

$$\cos \text{H. A. } 16° 57' 15'' = 9.98070$$

$$\sin l\ 48° 9' 30'' = 9.87215 \qquad \cos l = 9.82417$$

$$\sin d\ 22° 45' 28'' = 9.58753 \qquad \cos d = 9.96480$$

$$\log A = 9.45968 \qquad \log B = 9.76967$$

$$A = .28819 \qquad B = .58840$$

$$A = .28819$$

$$\text{Nat. } \sin a = A + B = .87659$$

$$\text{Whence, } a = 61° 14'$$

$$\text{Obs. Alt. } \ominus = 61° 11' 55''$$

$$\text{Cal. Alt. } \ominus = 61° 14' 0''$$

Alt. Diff., or intercept = 2′ 5″(−), or *from* the observed body

21. The data by which the point of intersection is calculated are now as follows: Assumed, or dead-reckoning, position, 47° 48′ N and 33° 45′ W; azimuth and intercept at first sight, N 76° 30′ E, 12.7 miles (+); at second sight, S 34° E, 2 miles (−); and run, N 75° E, 83 miles. Transferring the azimuths, paying attention to signs of intercepts, they become:

For intercept 2 miles the azimuth is N 76° 30′ W
For intercept 12.7 miles the azimuth is N 34° E

The angle subtended by azimuth lines in this case exceeds 90°, hence its supplement is used; or,

$$A = 180° - (34° + 76° 30') = 69° 30'$$

From Table I, the factors corresponding to this angle and intercepts are obtained; thus,

For intercept 2 and 69° the factor is 2.1
For intercept 12.7 and 69° the factor is 13.6

Entering these factors in a traverse with converted azimuths, the resulting difference of latitude and departure are as follows:

TRAVERSE

Azimuths	Factors	D. Lat.		Dep.	
		N	S	E	W
N 76° 30′ W	2.1	2.04	——	——	0.51
N 34° E	13.6	7.61	——	11.27	——

D. Lat. = 9.6′ N   Dep. = 10.7′ E
D. Long. = 16′ E

Lat. at second sight	= 48° 9.5′ N	Long.	= 31° 45′ W
D. Lat.	= 9.6′ N	D. Long.	= 16′ E
Lat. in	= 48° 19.1′ N	Long. in	= 31° 29′ W

22. The position at second sight is obtained, as already shown, by applying to the dead-reckoning position the difference of latitude and departure due to run between sights. The final fix of the ship's position at second sight may also be found by entering in the foregoing traverse the course and distance run between sights and by applying the resulting difference of latitude and difference of longitude to the original, or dead-reckoning, position. In doing this, however, it must be remembered that the difference of latitude and departure used in the preceding traverse are reversed when picked out from the Traverse Tables while the difference of latitude and departure for the run are picked out direct. By bearing this in mind the use of a common traverse will produce similar results as shown below, where the quantities marked with asterisks are reversed.

TRAVERSE

Azimuths	Factors	D. Lat.		Dep.	
		N	S	E	W
N 75° E	83	21.5	——	80.20	——
N 76° W	2.1	2.04*	——	——	0.51*
N 34° E	13.6	7.61*	——	11.27*	——

D. Lat. = 31.15′ N

91.47′
.51
Dep. = 90.96′ E
D. Long. = 136′ = 2° 16′ E

Lat. D. R.	= 47° 48′ N	Long. D. R.	= 33° 45′ W
D. Lat.	= 31′ N	D. Long.	= 2° 16′ E
Lat. of fix	= 48° 19′ N	Long. of fix	= 31° 29′ W

In Fig. 11 are shown the two lines of position considered and the resulting true position.

EXAMPLE.—On September 16, 1910, in latitude 30° 16′ S and longitude 15° 56′ W, an altitude of the sun's lower limb, taken at about 10 A. M., measured 45° 2′. The chronometer at time of sight showed $10^h\ 59^m\ 2^s$. The sun's azimuth was N 46° E. After a run S 9° E, 6 miles, a second

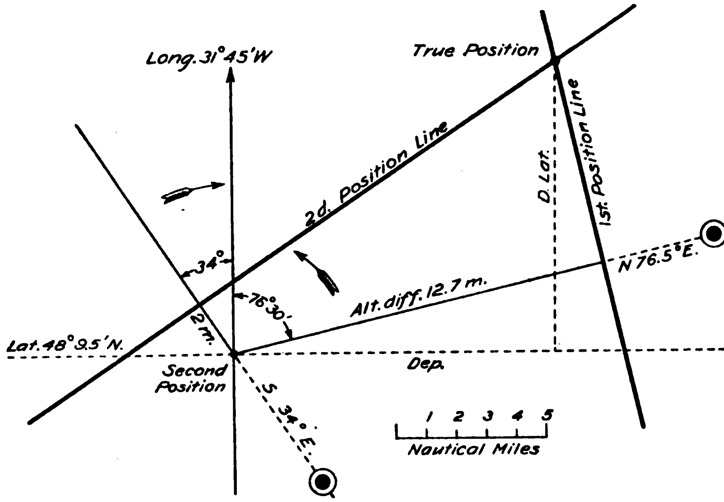

FIG. 11

altitude of the sun measured 52° 58′ when the chronometer indicated $0^h\ 2^m\ 39^s$. Bearing of sun at second sight was N 25° E. The error of the chronometer on Greenwich mean time was $2^m\ 18^s$, fast. Height of eye = 20 feet. Find, by St. Hilaire's method, the two lines of position and calculate their point of intersection.

SOLUTION.—Find, first, the approximate Greenwich mean time; thus,

$$
\begin{array}{rl}
\text{L. M. T., Sept. } 16 = & 10^h\ 0^m\ \ 0^s \text{ A. M.} \\
\text{Or, Sept. } 15 = & 22^h\ 0^m\ \ 0^s \text{ P. M.} \\
\text{Long. (W) in time} = & \underline{\ \ 1^h\ 3^m\ 44^s} \\
\text{Approx. G. M. T., Sept. } 16 = & 23^h\ 3^m\ 44^s
\end{array}
$$

$$
\begin{array}{rl}
\text{Chron.} = & 10^h\ 59^m\ \ 2^s \\
\text{Error (fast)} = & \underline{-\ \ \ \ 2^m\ 18^s} \\
\text{G. M. T., Sept. } 15 = & 10^h\ 56^m\ 44^s \text{ A. M.} \\
\text{Or, Sept. } 15 = & 22^h\ 56^m\ 44^s
\end{array}
$$

Then find the hour angle and calculate the intercept at each sight, keeping in mind the signs of l and d; thus,

$\odot$ Decl., Sept. 16 = N 2° 53′ 10.2″	Change in 1^h = 57.82″
Corr. for 1.1^h = + 1′ 3.6″	×1.1
$\odot$ Corr. Decl. = N 2° 54′ 13.8″	Corr. = 63.602″
Eq. of T., Sept. 16 = 4^m 54.73^s	Change in 1^h = $.887^s$
Corr. for 1.1^h = − $.98^s$	×1.1
Corr. Eq. of T. = 4^m 53.75^s (+)	Corr. = $.9757^s$
G. M. T., Sept. 15 = 22^h 56^m 44^s	Obs. Alt. $\underline{\odot}$ = 45° 2′ 0″
Eq. of T. = + 4^m 54^s	Dip = − 4′ 23″
G. App. T., Sept. 15 = 23^h 1^m 38^s	44° 57′ 37″
Long. (15° 56′ W) in time = 1^h 3^m 44^s	S. D. = + 15′ 57″
L. App. T., Sept. 15 = 21^h 57^m 54^s	45° 13′ 34″
H. A. = 2^h 2^m 6^s	Par. Ref. = − 51″
Or = 30° 31′ 30″	a = 45° 12′ 43″
	cos H. A. 30° 31′ 30″ = 9.93521
sin l 30° 16′ = 9.70245 (−)	cos l = 9.93636
sin d 2° 54′ 14″ = 8.70467	cos d = 9.99944
log A = 8.40712	log B = 9.87101
A = .02553 (−)	B = .74303
	A = .02553 (−)
	Nat. sin $a = A + B$ = .71750
Obs. Alt. $\ominus$ = 45° 12′ 43″	Whence, a = 45° 50.9′
Cal. Alt. $\ominus$ = 45° 50′ 54″	
Alt. Diff., or intercept = 38′ 11″	

Or = 38.2 mi. (−), or *from* observed body

Chron. = 0^h 2^m 39^s
Error (fast) = − 2^m 18^s
G. M. T., Sept. 16 = 0^h 0^m 21^s
$\odot$ Decl., Sept. 16 = N 2° 53′ 10″
Eq. of T., Sept. 16 = 4^m 55^s (+)

Run S 9° E, 6 mi. D. Lat. = 5.9′ S Dep. = .9′ E

D. R. Lat. = 30° 16′ S	D. R. Long. = 15° 56′ W
D. Lat. = 5.9′ S	D. Long. = 1′ E
Lat. in = 30° 21.9′ S	Long. in = 15° 55′ W
G. M. T., Sept. 15 = 24^h 0^m 21^s	Obs. Alt. $\underline{\odot}$ = 52° 58′ 0″
Eq. of T. = + 4^m 55^s	Dip. = − 4′ 23″
G. App. T., Sept. 15 = 24^h 5^m 16^s	52° 53′ 37″
Long. (15° 55′ W) in time = 1^h 3^m 40^s	S. D. = + 15′ 57″
L. App. T., Sept. 15 = 23^h 1^m 36^s	53° 9′ 34″
H. A. = 58^m 24^s	Par. Ref. = − 38″
Or = 14° 36′	a = 53° 8′ 56″

$$\cos \text{H. A. } 14^\circ\ 36' = 9.98574$$

$$\sin l\ 30^\circ\ 21.9' = 9.70373\ (-) \qquad \cos l = 9.93592$$

$$\sin d\ 2^\circ\ 53'\ 10'' = \underline{8.70201} \qquad \cos d = \underline{9.99945}$$

$$\log A = 8.40574 \qquad \log B = 9.92111$$

$$A = .02545\ (-) \qquad B = .83390$$

$$A = \underline{.02545(-)}$$

$$\text{Nat. } \sin a = A + B = .80845$$

$$\text{Whence, } a = 53^\circ\ 56'\ 42''$$

$$\text{Obs. Alt. } \ominus = 53^\circ\ \ 8'\ 56''$$

$$\text{Cal. Alt. } \ominus = \underline{53^\circ\ 56'\ 42''}$$

$$\text{Intercept} = \quad 47'\ 46''$$

Or = 47.8 mi. (−), or *from* observed body

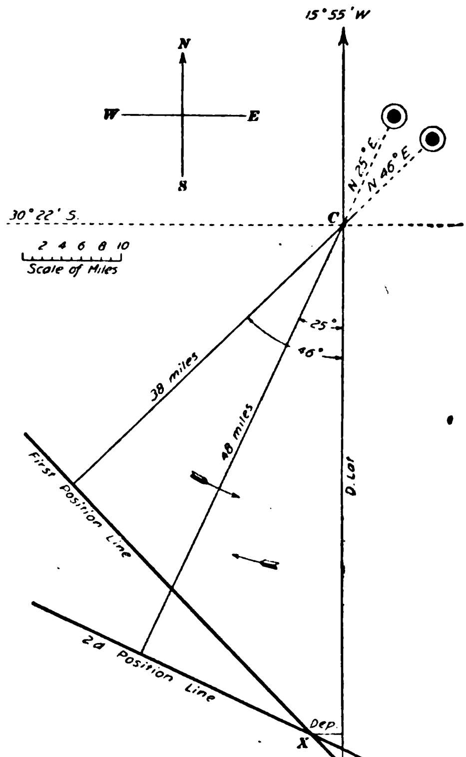

FIG. 12

23. From the preceding calculations, the following data for computing the final fix are now available: Assumed, or

dead-reckoning, position corrected for run, latitude 30° 22′ S, longitude 15° 55′ W, and azimuth and intercept at first sight, N 46° E 38 miles (−); at second sight, N 25° E, 48 miles (−). Both intercepts being negative, they are reversed and laid out accordingly, as shown in Fig. 12. The usual transfer of azimuths is then made:

For intercept 38 miles the azimuth is N 25° W
For intercept 48 miles the azimuth is S 46° E

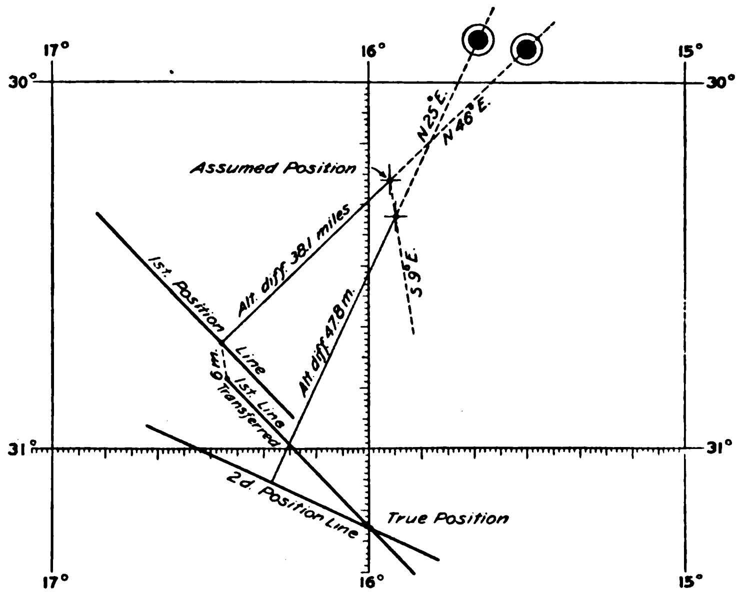

Fig. 13

The angle subtended by azimuth lines, or

$$A = 46° - 25° = 21°$$

Consulting Table I, the factors corresponding to this angle and intercepts are obtained; thus,

For intercept 38 and 21° the factor is 106.0
For intercept 48 and 21° the factor is 134.0

Entering the factors in a traverse as usual, the resulting difference of latitude and the departure are as follows:

TRAVERSE

Azimuths	Factors	D. Lat.		Dep.	
		N	S	E	W
N 25° W	106	44.8	——	——	96.1
S 46° E	134	——	96.4	93.1	——

D. Lat. = 51.6′ S Dep. = 3′ W

Lat. second sight = 30° 22′ S	Long. = 15° 55′ W
D. Lat. = 51.6′ S	D. Long. = 3.5′ W
Lat. in = 31° 13.6′ S	Long. in = 15° 58.5′ W

On the chart, Fig. 13, where the true position of the ship is found by plotting, it will be noticed that the result obtained agrees with the calculated fix.

ADVANCE CALCULATION OF SECOND ALTITUDE

24. One of the advantages of the St. Hilaire method not yet referred to is the facility by which the work of computing the second altitude can be prepared in advance. Thus, after the first observation is made and the resulting intercept and position line are plotted, the navigator may select, in advance, any desired Greenwich mean time and work out the altitude corresponding to this time and the ship's position at that time. When the predetermined moment is at hand, all the observer has to do is to measure the altitude, reduce it to true, get the intercept, or altitude difference, and plot it on the chart. The resulting true position of the ship may thus be fixed within a few minutes after taking the second sight.

If for some reason the observer should fail to measure the altitude at the exact moment, the longitude of the assumed position may be changed to agree with the hour angle at the time the altitude was actually measured.

25. For example, suppose the dead-reckoning position of the ship is at *a*, Fig. 14, or in latitude 30° 32′ N and longitude 26° 17′ W. When the true bearing of the sun is S 60° E and

the chronometer indicates Greenwich mean time $10^h\ 11^m\ 40^s$ the intercept resulting from sight taken at that time is 9 miles (−). This gives a line of position *m n*, Fig. 14. For the next few hours, the ship is expected to run a steady course N 46° W, making a speed of 14 knots. The navigator decides

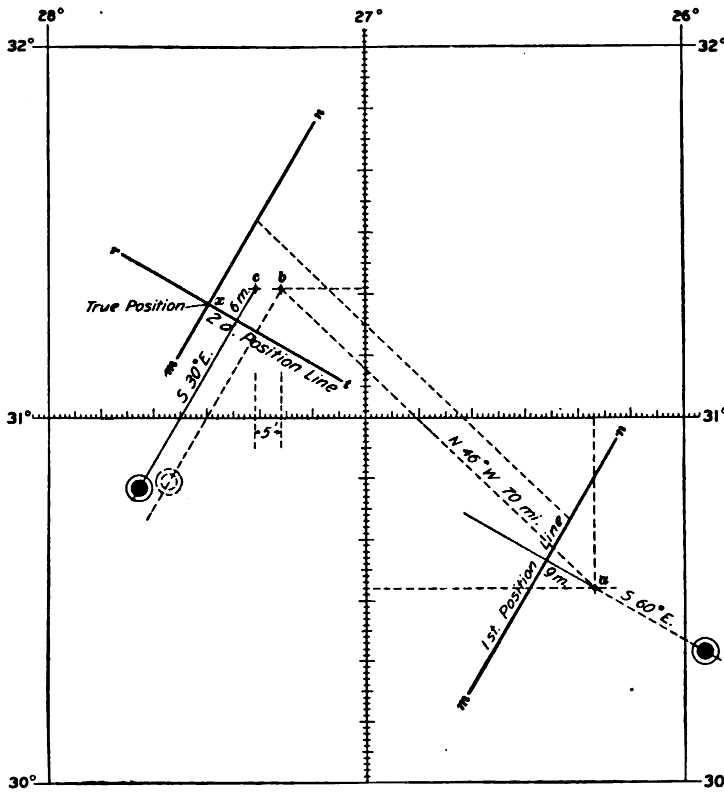

FIG. 14

to make his second sight 5 hours later, or when the Greenwich mean time is $15^h\ 11^m\ 40^s$, and calculate his altitude in advance. The dead-reckoning position when second sight is taken should accordingly be latitude 31° 20.6′ N and longitude 27° 16′ W, obtained by allowing for course and the distance of $5 \times 14 = 70$ miles to be run in the interval.

This latitude and longitude must therefore be used in calculating the second altitude.

26. At the selected time the sun is partly clouded, but 20 seconds later, or when the chronometer shows $15^h\ 12^m$, the altitude of the sun is measured. The true azimuth at that time is S 30° E and the intercept obtained is 6 miles (+).

As the Greenwich mean time at instant of measuring the altitude was 20^s later than the Greenwich mean time used in calculating the altitude, the longitude for the second line must be changed to conform with this difference. In other words, the second position *b*, Fig. 14, must be shifted to the west a distance equal to 20 seconds of time or 5 minutes of arc. This gives the point *c* from which the second azimuth and intercept should be plotted. The resulting line of position *r t* will now intersect the first line *m n* (transferred) at *x*, which is the true position of the ship at time of taking the second sight.

27. If the second altitude had been observed 20 seconds ahead of, or earlier, than the selected Greenwich mean time ($15^h\ 11^m\ 20^s$), the point *b* would have to be shifted 5 minutes to the east. In other words, when the Greenwich mean time at sight is greater than that of the computed altitude, the point must be shifted to westward; if less, to the eastward. In this way the calculations for second altitude may be prepared in advance provided the course and distance to be run can be estimated with a fair degree of accuracy.

CAUTIONARY REMARKS ON NAVIGATION

28. Trustworthy Charts.—Before leaving port for any voyage, a vessel should be well equipped with navigating charts covering not only the routes along the contemplated trip but that of any locality where there is a possibility of call. Charts are published by the government and can be bought directly from the United States Coast and Geodetic Survey and from the United States Hydrographic Office, in Washington, D. C.; or, they may be obtained from any of the agencies or the branch offices of the latter, which are located in the principal harbors along the coast.

The best way in which to order charts needed for any trip is to do so by the aid of a catalog issued by the institutions mentioned. Copies of catalogs from the Coast and Geodetic Survey may be obtained free of charge on application to the superintendent, while for the catalog of Hydrographic Office charts, a charge is made of 50 cents for each copy. The arrangement of these catalogs is very simple and readily understood.

As a matter of prudence it is well to be supplied with charts covering any intended route, or routes, as exigencies may develop where it is necessary to seek ports not originally intended for call. The cost of charts is so low, varying between 25 and 50 cents a copy, as to exclude any excuse for not being provided with reliable charts when needed.

29. Departure Fix.—When beginning a voyage, care should be taken to establish a good point of departure, which should be obtained, if possible, by two or more bearings of well-identified objects on shore. This point of departure should be plotted on the chart and from it the first course should be shaped. To make sure of the correct fixing of this point and to verify its position additional bearings of known objects should be observed before they are lost to sight. If the run

to be made includes a portion of a coast line, it is well to check up from time to time, by cross-bearings, the position of the ship until permanent landmarks are finally left out of sight.

It is not always advisable to rely on anchored buoys for such bearings, as buoys are frequently out of place. Not even light ships may be in the exact spot for which they are marked on the chart. For the purpose of establishing a point of departure permanent landmarks should for this reason be selected.

30. At the time of taking the departure, the reading of the patent log should be carefully noted and recorded, as from that moment the distance run will be indicated by the log. If a patent log is not used and the speed is ascertained by an ordinary chip log, or by the revolutions of the engine, the time at which the bearings are taken (and the point of departure established) should be accurately noted. Whenever available, a sounding should be taken at that moment also, to aid in verifying the point of departure. The bearings, reading of log, exact time of observing, and the depth of sounding should all be noted in the log book.

31. Shaping Compass Courses.—When shaping a course through regions of the sea where the magnetic variation changes rapidly, an estimate of the day's run should be made, noting the different values of the variation for the next 24 hours. The mean value of the variations thus found is then used to find the compass course to be run during the coming 24 hours. Or, the course may be shaped for intervals of 4 hours, applying variation for the distance estimated to be covered in the run. Thus, if the change in variation is 6° for a 24-hour run, or the variation changes from 9° W to 15° W, the mean value 12° W is used to shape the compass course; or, by selecting runs of 4 hours, the course may be changed 1° at the termination of each 4-hour run.

When shaping courses to be run, due consideration must be given the effects of currents and tides prevailing in the locality through which the run is to be made. To allow for such currents, the methods described in *Dead Reckoning* under

the heading Current Sailing should be used. The set and drift of currents and the direction and duration of tides in all localities where they have been investigated may be found on charts and in Sailing Directions.

32. Dependence of Dead Reckoning.—As explained in *Dead Reckoning*, under the heading of Departure Course, the bearing and distance found in locating the point of departure is reversed and entered in the log book and in the traverse as an ordinary course and distance run. A careful record is then kept of all the courses and distances run and the time spent on each course. These data are used in checking and fixing the ship's position by dead reckoning.

The degree of dependence that can be placed on dead reckoning is contingent, in a great measure, on the record kept of all data used in that method. If courses are accurately run and bad steering is avoided, if the logs are working properly and the run is made in fairly good weather and moderate sea, the result by dead reckoning should be as good as that obtained by celestial observations. Even in heavy weather, dead reckoning should be dependable provided the effect of sea and wind is fairly estimated.

There are records of transatlantic liners having made the passage from England to America, and vice versa, in thick weather and on dead reckoning alone without having obtained a single sight either celestial or terrestrial from the time of leaving until entering the port of destination. This shows the value of dead reckoning when courses and distances have been accurately estimated.

33. The only disturbing elements are unknown currents, bad steering, and a poorly compensated compass. Currents, whether known or not, are uncertain factors and are liable to upset the most painstaking dead reckoning. However, by using the methods of current sailing heretofore explained, in combination with up-to-date charts, on which the latest notations on prevailing currents are recorded, the errors in dead reckoning due to currents are reduced to a minimum.

Careless steering is often the real cause of discrepancies in fixes by dead reckoning and by sights. Quite frequently such discrepancy is erroneously attributed to the effect of currents.

Poor steering is less noticeable aboard ships carrying trained quartermasters than on ships where sailors take their turn at the wheel. The habit of many wheelsmen in watching the compass card from one side of the wheel instead of taking a position directly in front of the binnacle has much to do with faulty steering.

34. Watchfulness Over the Compass.—In *Deviation and Compass Compensation* there was pointed out in detail the various errors attached to the magnetic compass and the best means to reduce and tabulate such errors. The fact cannot be too strongly impressed on the inexperienced navigator that watchfulness of the compass is one of the first requisites in the successful handling of a deep-sea going ship. After the compass is carefully compensated and all errors tabulated, it becomes the duty of the navigator to see that the compass is kept free from all magnetic disturbances and to ascertain by means of azimuth observations any change in its performance. This applies in particular to the compass selected as standard. If a steering compass is used, all courses must be set by the standard compass and frequent comparison between the two should be made during a trip. With the compass in good order and carefully watched, fixes by dead reckoning will be more dependable.

35. Navigator's Routine Work.—The routine work of a navigator when at sea includes, beside dead reckoning, at least one morning sight for hour angle, a meridian altitude at noon for latitude, and one afternoon sight for hour angle. This, it must be remembered, is the minimum. Good practice requires additional sights taken at suitable intervals during the day; each sight is to be worked for a line of position either by Sumner's or by St. Hilaire's method.

Thus, in the morning when the sun is near or on the prime vertical, a series of altitudes is taken, using the mean in working out the sight; at the same time, the azimuth by compass,

the reading of the patent log, and the heading of the ship are noted. A second sight may be taken an hour or so later, or when the azimuth of the sun has changed at least 30°, due care being taken to note the exact run between the sights. The second line of position thus found is then combined with the first line in the usual manner.

36. If there is a probability of the weather being cloudy at noon, a cautious navigator will secure sights not later than ½ hour before apparent noon and then, in case the meridian altitude is lost, work them out by whatever method is best suited to find the latitude. Should no sight be taken before noon on account of cloudiness any chance to secure sights immediately after noon or within ½ hour after apparent noon should not be neglected. Indeed, even though the weather is clear before and after noon, it is good practice to take all sights referred to beside the meridian altitude at high noon. Such sights, when worked out, will serve as useful checks on the positions obtained.

37. The principal data that the navigator should prepare at noon each day may be summed up as follows:

1. Latitude and longitude at noon by dead reckoning, found by working the traverse from the previous noon, or point of departure.
2. Latitude and longitude at noon found by observations of the sun and by the intersection of position lines.
3. Course and distance made good from the noon position of the previous day to the noon position determined by observations.
4. Set and drift of current obtained by taking the difference between the dead-reckoning position and the observed position, as explained in *Dead Reckoning*.
5. The deviation of the compass, usually on the heading of the ship at time of taking the A. M. sight.
6. Course and distance to point of destination; or, the course to be run for the next 24 hours. If not taken from chart, the course and distance are calculated by middle latitude or Mercator's Sailing.

38. The afternoon sights are similar to those in the forenoon, the latitude used being that carried forwards from noon to time of sight.

During any time of the day, if the weather begins to cloud and the chances are that the sun will be obscured for some time, perhaps the entire day, a sight, or number of sights, should be taken before it is too late to do so.

39. Observations of Stars.—Observations of stars are very valuable to the navigator and should, therefore, be taken whenever available. It sometimes happens that after a day of foggy weather the sky becomes clear at night, presenting a fine opportunity to the navigator to ascertain his position by sights of well identified stars.

In order to obtain good results by observations of a star two things are essential: First, the star must be identified without doubt; second, the horizon must be well defined. With a muddy and uncertain horizon, the resulting sight is not to be depended on. Hence, such observation should be made preferably at dusk, or during morning and evening twilight. During bright moonlight, sights of stars may be taken, but much dependence cannot be placed on results unless the observer is sufficiently skilled in measuring altitudes with a poorly defined horizon. The twilight period is much to be preferred for observation of stars, because the sea horizon is then, as a rule, quite distinct and clear. It is only when cloudy weather at twilight prevents observations of stars that the moonlit horizon may be used at night.

40. During the hours of twilight, owing to the large number of first- and second-magnitude stars available, with a right ascension ranging from 1 to 24 hours, three or four such stars may be selected so situated that the resulting lines of position will intersect at nearly right angles. Such intersections obtained from star sights should prove of much value in fixing and checking the ship's position.

41. Identification of Stars Essential.—A very important factor in connection with star observations is the identification of the stars selected. Navigators should study carefully

the relative position of stars most likely to be used for observations in order that no mistakes are made, or uncertainty felt, as to what star is observed. The same applies to the identification of planets used for navigational work.

To facilitate identification of stars, the Hydrographic Office publishes tables known as *Star Identification Tables*. In these tables are given simultaneous values of the declination and hour angle corresponding to the values of the latitude, altitude, and azimuth ranging from 0° to 88° in latitude and altitude, and from 0° to 180° in azimuth.

Besides these tables, there are various graphic methods of identifying stars. Those proposed by Sigsbee, Rust, Littlehales, and De Aquino are among the best. Nautical supply houses acting as agencies for the sale of Hydrographic Office publications are usually able to furnish descriptions of these methods, with the exception of that by Rust, which is published by the United States Naval Institute, Annapolis, Maryland.

42. In the supplement of the American Nautical Almanac, published by the Nautical Almanac Office, a very useful table is included giving the mean time of transit of not less than 55 stars for every day throughout the year. In selecting stars in transit for latitude determinations, this table will be found very convenient.

43. Importance of Dependable Chronometers.—As the element of time is very important in most methods of determining the position of a ship, particular care should be given to the chronometer and its performance. Its error and daily rate should be frequently noted, especially just before leaving port, and care should be taken to maintain a uniform rate during the trip by means of systematic winding and by preventing the chronometer from being exposed to marked changes in temperature.

44. Every important seaport of the world now has established time signals, displayed at certain defined instants. If time balls are not in use, signals are received by telegraph by which the chronometer may be rated. For the convenience

of vessels under way, time signals are now sent out from government radio stations and vessels equipped with receiving instruments are thus enabled to verify their chronometer error. From the naval radio stations at Arlington, Key West, and New Orleans, time signals are sent daily at noon and also at 10 P. M., 75th meridian time. On the west coast, radio time signals are sent daily except Sundays and holidays by the naval radio station at North Head, Eureka, Point Arquello, and San Diego at noon and at 10 P. M., 120th meridian time. For further particulars about time signals sent by radio, navigating officers of trans-oceanic vessels should apply to the Hydrographic Office, Washington, District of Columbia.

45. Discrepancies in Sights.—The question is often asked, how close may a fix be to the ship's actual position? In other words, what is the average error in the position of a ship as determined by observations of celestial bodies? In answering this question, it must be borne in mind that with the most painstaking work in obtaining the data needed the result will be approximate only. The imperfections of the sextant, a slight inaccuracy in measuring the altitude or in recording the Greenwich mean time, excessive refraction, and errors in estimating the distances run between sights contribute to render the result approximate. What then is the probable limit of dependence? Under favorable conditions and with careful work on the part of the observer and his assistant in noting the chronometer, the ship may be assumed to be within 2 miles of the position calculated; or, the position of the ship may be anywhere within a circle formed by the fix as a center and a radius of 2 miles.

46. In case the fix is determined by the intersection of two position lines, the area within which the ship is located is bounded by four auxiliary lines drawn, respectively, 1 mile on either side of the position lines establishing the fix. The parallelogram thus formed represents the limit of uncertainty in the ship's position and in shaping his course the navigator will give due allowance for this probability of error in his fix.

However, in actual practice this refinement is applied only when approaching a coast or in passing close to points considered difficult or fraught with an element of risk. In the open sea and with plenty of sea room, the fix obtained from good sights is usually marked on the chart as the actual position of the ship.

47. Refinement in the Working of Sights.—The use of seconds in working out sights is often a matter of divided opinion among experienced navigators. Those advocating the elimination of seconds in picking out logarithms claim that inasmuch as the ship's position even with good sights may be considered in error 1 or more miles, as explained, the use of seconds in working out sights is immaterial and useless. If the errors due to the elimination of seconds had the effect to offset errors due to instrumental and other imperfections, such a contention would be well founded. But as they may have an opposite effect and thus increase the errors of observation, it seems a matter of good practice always to work sights, both for latitude and longitude, with seconds.

If the navigator has at his disposal tables of logarithms giving functions to every 15 seconds of arc, this would be sufficiently close; but in the absence of such tables, it is advisable to follow the practice shown in solution of problems in this text, picking out logarithms corresponding to seconds of arc.

OCEAN METEOROLOGY

WIND AND WEATHER

THE ATMOSPHERE

1. Meteorology and the Nautical Profession.—By reason of the peculiarity of his profession, the navigator should, above all others, possess a good, practical knowledge of **meteorology**—the science that treats of the conditions and changes of the atmosphere.

A good insight into the navigational phases of this science, particularly the law of storms, will be found not only useful, but a real necessity in the navigation of the high seas. A few of the most important facts and principles of this science will therefore be explained in the following paragraphs.

2. Extent of Atmosphere.—The earth is entirely enveloped by a gaseous body known as the *atmosphere*. The height of this atmosphere is far greater than any height that can be reached by ordinary means, such as balloons, etc., but by measuring the thickness of the penumbra that surrounds the shadow of the earth on the moon at the time of an eclipse of the moon, its extent is estimated to be from 50 to 60 miles; it covers everything on the earth's surface with a pressure of nearly 15 pounds per square inch. The density of the atmosphere is a maximum at the surface of the earth, and gradually diminishes until the confines are reached, where the density is zero.

3. The atmosphere is composed of air, just as the ocean is composed of water. The chief ingredients of air are *oxygen* and *nitrogen;* of these, oxygen is the most important, because its inhalation by human beings and animals is essential to life.

4. Heat.—Heat is not a substance, but may be considered as a form of energy. It is due to the rapid motion of minute particles, called *molecules*, of which all bodies are composed. Thus, when a person feels cold, he may, by rapid motion, for instance, by running, increase the warmth of his body.

5. Temperature.—The different states that a body is in, according to the amount of sensible heat it possesses, are indicated by the word **temperature.** In meteorology temperature refers to the condition of the atmosphere in relation to its sensible heat and cold.

THE THERMOMETER

6. Explanation of Principles.—The instrument used for making accurate measurements of the temperature of gaseous and other bodies is called a **thermometer,** or *heat measurer.* In this instrument, the most common method is to utilize the expansive effect of heat on liquids. The liquids used are mercury and alcohol, the former being used because it boils only at a very high temperature, and the latter because it does not solidify at the greatest known cold produced by ordinary means.

In Fig. 1 is shown a mercurial thermometer with two sets of graduations on it. The one on the left, marked *F*, is the **Fahrenheit thermometer,** so named after its inventor, the German physicist Fahrenheit; this thermometer is the one commonly used in the United States and England. The one on the right, marked *C*, is the **centigrade thermometer** proposed by the Swedish mathematician Celsius; it is used by scientists throughout the world on account of the graduations being better adapted for calculations.

As will be seen, the instrument consists of a glass tube that has a bulb at one end and is closed at the other, so as to keep out air. Before closing the upper end, the tube is partly filled with mercury, and the air above it is driven out by heating the mercury to near its boiling point, when the tube above the mercury will be filled with mercurial vapor. The glass tube is now sealed, and, on cooling, the vapor condenses and a vacuum results. The expansion or contraction of the mercury by applying or withdrawing heat from the body with which the bulb is in contact, causes the highest point of the mercury column to rise or fall, and, since for equal changes of temperature the mercury rises or falls equal distances, this instrument, when properly made and graduated, indicates any change in temperature with great accuracy.

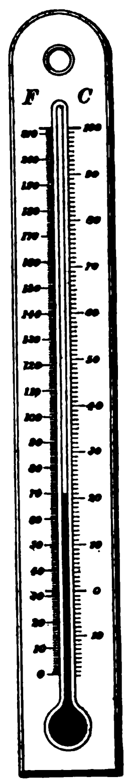

FIG. 1

7. Thermometer Graduations.—In order to graduate a thermometer, it is placed in melting ice, and the point to which the mercurial column falls is marked *freezing*. It is then placed in the steam rising from water boiling in an open vessel, and the point to which the mercurial column rises is marked *boiling*. Two fixed points, the freezing and the boiling point, are thus established. If it is desired to make a Fahrenheit thermometer, the distance between these two fixed points is divided into 180 parts, called *degrees*. The freezing point is marked 32° and the boiling point 212°; 32 parts are marked off from the freezing point downwards, and the last one is marked 0°, or zero. The graduations are carried above the boiling point and below the zero point as far as desired. This thermometer was invented in 1714, and was the first to come into general use. In graduating a centigrade thermometer, the freezing point is marked 0°, or zero, and the boiling point 100°. The distance between the freezing and boiling points is divided into 100 equal

parts; these equal divisions are carried as far below the freezing point and above the boiling point as desired. When there is any doubt as to the thermometer used, the first letter of the name is placed after the degree of temperature. For example, 183° F. means 183° above zero on the Fahrenheit instrument, and 183° C., that the temperature is 183° above zero on the centigrade instrument.

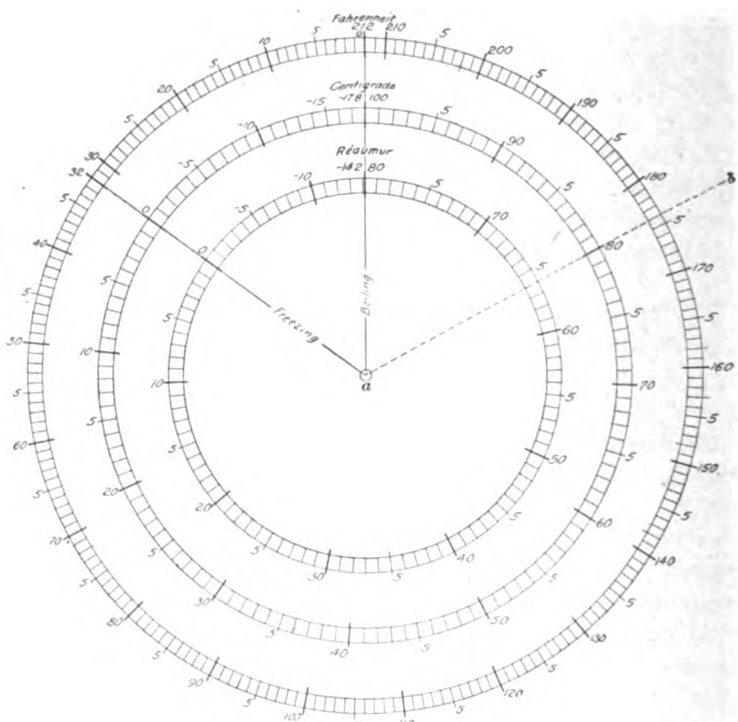

FIG. 2

In Russia and in certain parts of Germany, another thermometer, called the **Réaumur**, is used. The freezing point is marked 0°, or zero, and the boiling point 80°, the space between these two points being divided into 80 equal parts; 183° R. means 183° on the Réaumur thermometer.

8. In order to distinguish the temperature below the zero point from that above, the minus sign (–) is placed before the figures indicating the number of degrees below zero, and the plus sign (+) for those above. Thus – 18° C. means that the temperature is 18° below the zero point on the centigrade thermometer, and – 25.4° F., that it is 25.4° below zero on the Fahrenheit thermometer.

9. To Convert the Reading of One Thermometer Into That of Another.—It is sometimes necessary to change the reading of one thermometric scale into that of another; for instance, when the temperature is given in degrees of Fahrenheit, to find the corresponding value on either Réaumur or centigrade, and conversely. By using the accompanying thermometric chart, Fig. 2, this is very readily accomplished. Simply place a ruler or the straightedge of a sheet of paper along the center *a* and the given degree on either of the circles representing the scale of the given thermometer; the intersection of this edge with the other circles will give the corresponding degree on the respective scales.

ILLUSTRATION.—A centigrade thermometer shows a temperature of 80°. Find the corresponding temperature on a Fahrenheit and a Réaumur thermometer.

Proceed as follows: Place the edge of a ruler in the position indicated by the straight line *a b*, Fig. 2 that is, along the center *a* and the 80° mark on the centigrade scale. The corresponding temperature, as indicated by the intersection of this line with the other scales, will then be 64° on Réaumur and 176° on Fahrenheit thermometers, very nearly.

THE BAROMETER

10. The atmosphere, light and unsubstantial as it appears to the average observer, has, as already stated, a positive weight and as such it exerts a considerable pressure on the earth's surface. The amount of this pressure varies with the altitude and the density of the air, being greatest at sea level and decreasing gradually with the increase of altitude. The pressure of the atmosphere, therefore, would be

practically the same at all places having a common altitude above the level of the sea if it were not for the disturbing influence of the solar heat and of the movement of the air caused by its unequal heating at different places on the earth.

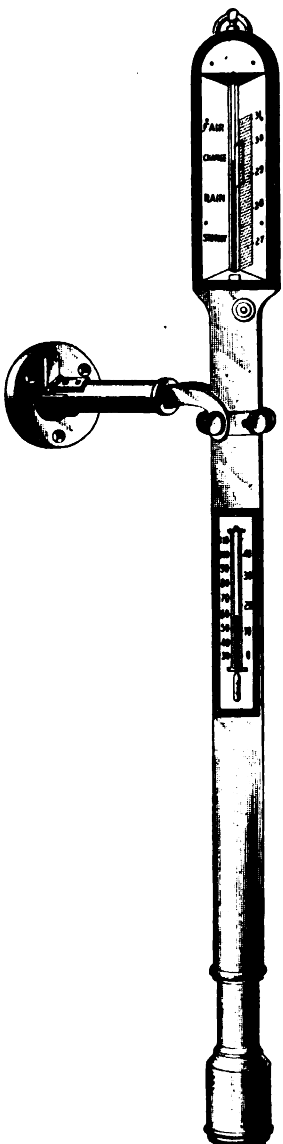

FIG. 3

The instrument used for measuring the pressure of the atmosphere is called the **barometer.** There are two kinds in general use—the *mercurial* and the *aneroid barometer.*

11. Mercurial Barometer. The **mercurial barometer** is shown in Fig. 3. The principle of this instrument may be explained as follows: A glass tube *a*, Fig. 4, about 3 feet long and $\frac{1}{3}$ inch in diameter, closed at one end, is filled with mercury. The open end is then closed with a finger, and the tube is turned over and inserted into a vessel, or cup, *b*. Some of the mercury will now flow downwards, out of the tube and into the cup, until the weight of the mercury remaining in the tube is equal to the pressure of the air on the surface of the mercury in the cup. The space above the mercury in the tube will be practically a vacuum; consequently, there will be no pressure on the top surface of the mercury in the tube. It is evident, then, that, when the pressure of the atmosphere on the surface of the mercury in the cup increases, the mercury in the tube is forced

upwards, and that when the pressure decreases, the mercury in the tube falls. It is on this principle that the barometer shown in Fig. 3 is constructed. The tube and the cup at the bottom of the instrument are protected by a casing of brass or some other metal. At the top of the tube is a graduated scale that can be read by means of a vernier to $\frac{1}{100}$ inch, which is quite sufficient for nautical purposes. An accurate thermometer is usually attached to the casing for the purpose of determining the temperature of the outside air at the time the barometric reading is made. This is necessary, since mercury expands when the temperature increases and contracts when the temperature falls. For this reason a standard temperature is assumed, to which all barometric readings are reduced. This standard temperature is usually taken at 32° F., when the height of the mercurial column is 30 inches.

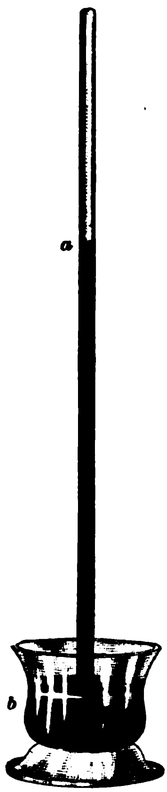

FIG. 4

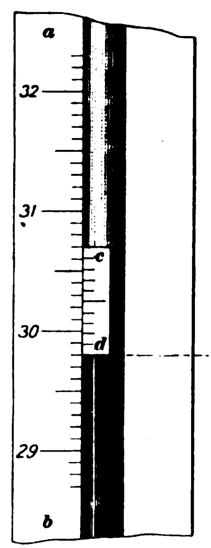

FIG. 5

The barometer being a very delicate instrument, requires careful handling. When suspended for use, the instrument should hang freely in a vertical position and in a place where it is protected from the rays of the sun and from all other local sources of heat or cold.

12. How to Read a Mercurial Barometer.—In reading off a barometer, the lower edge of the vernier is brought into contact with the uppermost point of the mercury when

the eye is at an equal height and looking horizontally at the tube. For instance, let *a b*, Fig. 5, represent a portion of the scale of a barometer, *c d* the vernier, and *e* the top of the mercurial column. The vernier is then placed in the position shown, and the barometric pressure is read off in the same way as the sextant, the whole and tenths of an inch being read on the scale, and the hundredths of an inch on the vernier, as indicated by a division on the vernier coinciding with a division on the scale.

13. Aneroid Barometer.—The **aneroid barometer** is shown in Fig. 6. These instruments are made in various

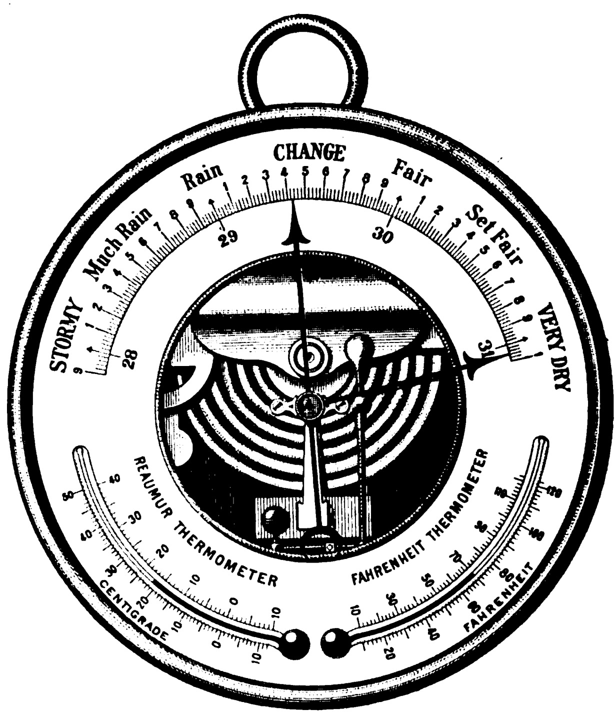

Fig. 6

sizes, from the size of a large watch up to an 8- or 10-inch face. They consist of a cylindrical box of metal, with a top of thin, elastic, corrugated metal. The air is removed from

the box. When the atmospheric pressure increases, the top is pressed inwards, and when it diminishes, the top is pressed outwards by its own elasticity, aided by a spring beneath. These movements of the cover are transmitted and multiplied by a combination of delicate levers that act on an index hand and cause it to move either to the right or to the left over a graduated scale. These barometers are self-correcting (compensated) for variations in temperature. They are portable, and are so very delicate (when carefully made) that they show a difference in atmospheric pressure when transferred from the upper part of a room to the floor. The instruments should be handled with extreme care, as they are easily injured. A good aneroid barometer, costing from $20 to $30, is of great value to the navigator as a "weather glass" if carefully observed, but its readings are not so accurate as those of a good mercurial barometer.

14. Meaning of Barometric Changes.—In order to understand the meaning of changes in the atmospheric pressure, as indicated by changes of the mercury column in a barometer, reference is made to Fig. 7, which represents a weather map, such as is published daily by the United States Weather Bureau. On such a map there will, as a general rule, appear one or more approximately circular areas marked "Low," while other areas of a more irregular outline are marked "High." The first implies that the reading of the barometer within the area indicated is *below* the average height; the second, that it is *above* it. Around the area marked "Low" are drawn lines, each of which has a number attached. These lines are called *isobars*, and the attached numbers are barometric readings; thus, at all points along any one of these lines the reading of the barometer, at the hour represented by the chart, is the same. The point of lowest barometer, or point of least atmospheric pressure, is known as the *storm center*, inasmuch as it coincides very nearly with the area over which a storm prevails. Furthermore, when going from the center in any direction, it will be noticed that the atmospheric pressure increases between

each isobar; in other words, when receding from the center, the barometer will gradually rise, and, conversely, when approaching the center, it will gradually become lower. Now, since a storm is always moving, it is evident that whenever the barometer shows a tendency to drop below the average height, the navigator will know that an area of low pressure is approaching, and since this area indicates the

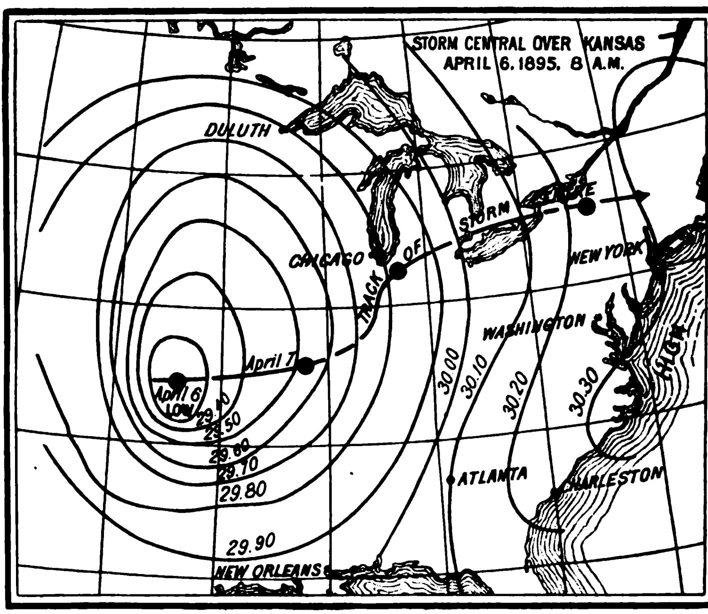

FIG. 7

presence of a storm of more or less intensity, he is thus warned of the impending change in weather.

From this the beginner will realize the important function of the barometer, and that by noting the changes of the mercurial column, an observer is able to foretell, with a fair degree of accuracy, any decided change in weather conditions. The use of the barometer as a weather forecaster will be further discussed under the heading Notes on Weather.

WINDS

15. When a large portion of air is put in motion, it is called a **wind**; and all winds, whether a hurricane or a gentle evening breeze, are caused directly or indirectly by changes in the temperature of the air. Thus, when from

TABLE I

BEAUFORT'S SCALE

Force of Wind	Velocity per Hour	
	Statute Miles	Nautical Miles
0. *Calm*. Full-rigged ship, all sail set, no headway . . .	0 to 3	0 to 2.6
1. *Light Air*. Just sufficient to give steerageway	8	6.9
2. *Light Breeze*. Speed of 1 or 2 knots, "full and by" . . .	13	11.3
3. *Gentle Breeze*. Speed of 3 or 4 knots, "full and by" . . .	18	15.6
4. *Moderate Breeze*. Speed of 5 or 6 knots, "full and by" .	23	20.0
5. *Fresh Breeze*. All plain sail, "full and by"	28	24.3
6. *Strong Breeze*. Topgallant-sails	34	29.5
7. *Moderate Gale*. Single-reefed topsails	40	34.7
8. *Fresh Gale*. Double-reefed topsails	48	41.6
9. *Strong Gale*. Lower topsails .	56	48.6
10. *Whole Gale*. Lower main topsail and reefed foresail . .	65	56.4
11. *Storm*. Storm staysails . . .	75	65.1
12. *Hurricane*. Under bare poles	90 and over	78.1 and over

any cause two neighboring regions become unequal in temperature, the air of the warmer region, being lighter, will ascend and spread out over the top of the colder air, while the heavier air of the colder region will flow in to supply its

place. A motion, or wind, is then produced, the swiftness, or velocity, of which will depend on the difference in temperature between the two regions. The greater the difference, the greater the velocity of the wind; and this wind, or rather these winds—one blowing from the colder regions to the warmer along the surface of the earth, the other from the warmer to the colder in the upper regions of the atmosphere—will continue to flow until equilibrium is restored. Another effect of the warm air ascending to the upper strata of the atmosphere is the formation of *clouds*. As the air rises it expands, and in doing so it is rarefied and cooled. Its vapor is then condensed into clouds or precipitated in rain. When air is at rest, it is said to be in a state of *calm*.

16. Force of Wind.—The Beaufort scale is commonly used by seamen for recording the force of wind. For the guidance of those unaccustomed to the use of this scale, the corresponding velocity per hour in statute and in nautical miles is shown in Table I.

As shown in this table, the force of wind varies from 0, a calm, to 12, a hurricane—the greatest velocity it ever reaches. Intermediate forces can be readily estimated by the personal judgment of the observer. To obtain accurate results in recording force and direction, the speed and course of the ship or steamer must be considered.

17. Classification of Winds.—Winds are, as a general rule, classified as *constant*, *periodical*, and *variable*, and are named according to the direction from which they come; that is, from the *true* bearing of the wind.

CONSTANT WINDS

18. Trade Winds.—The **trade winds** belong to the first-named class of winds. They blow unceasingly from northeast to southwest in the northern hemisphere, and from southeast to northwest in the southern hemisphere, their area of operation extending from about 30° N to 30° S, with a belt of calms between, commonly known as the *doldrums*.

The name *trade winds* was given these winds on account of their constancy in force and direction, as well as for the great service they render commerce and navigation.

For centuries the trade winds were a puzzle both to the meteorologist and to the mariner. The astronomer Halley was the first to suggest an explanation of the cause of these winds, and his theory, with a slight modification, is now accepted as correct. This explanation, briefly told, is as follows: It is well known that warm air is lighter than cold air. Therefore, the atmosphere at the equatorial regions of the earth, being heated to a considerable degree, will accordingly rise, and in its place will flow cold air from the direction of the poles.

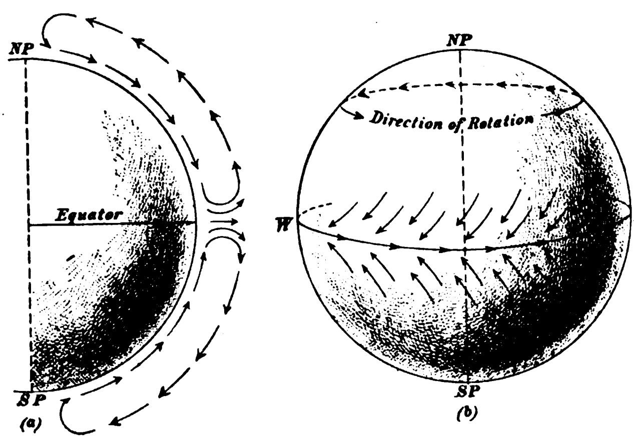

FIG. 8

A circulation of air is thus established, one current flowing from the equator toward the poles in the *upper* regions of the atmosphere, and another current flowing toward the equator from the poles along the *surface*, as indicated by the arrows in Fig. 8 (*a*). Now, if the earth were at rest, a northerly surface wind would consequently prevail in the northern hemisphere, and a southerly surface wind in the southern hemisphere. But these directions are modified by the earth's rotation. During their movement from the poles, the surface currents pass gradually by the latitude parallels, the diameters, and, consequently, the rotary

speed of which progressively increases; therefore, if their absolute velocity does not diminish, these currents will apparently move toward the west, as indicated in Fig. 8 (*b*), and their seeming direction will be from northeast to southwest, which is, in fact, the general direction of the trade winds in the northern hemisphere. A similar result follows in the southern hemisphere; the wind there, coming from the south, is influenced by two forces—one drawing it north, the other drawing it west—and will, by the law of the composition of forces, take an intermediate direction and blow from southeast toward northwest. All observations confirm this reasoning.

19. The regions of the trade winds are seldom invaded by storms. They are marked by the most pleasant weather conditions for which a navigator can possibly wish; they bear only small clouds by day, and the nights in these regions are nearly cloudless, being admirably adapted for star observations. There are times when the trade winds have a tendency to weaken or shift—this probably being caused by disturbing counter currents of air outside or near their limits—but, as a general rule, they blow with remarkable constancy, in both direction and velocity.

20. **The Doldrums.**—The **doldrums**, or *calm regions*, already mentioned, extend across the Atlantic and Pacific oceans, their general directions being parallel to the equator. They occupy very different positions at the close of the winter months than they do at the end of the summer months. They never cross the equator in the Atlantic Ocean. In the spring, the centers of these regions are only 1° or 2° north of the equator, while in the summer they frequently rise to latitude 9° or 10° N. These changes are directly influenced by the sun, advancing with that luminary to the northward during the summer, and retreating with it during the early winter months. The doldrums with their calm, sultry air, occasional baffling breezes, and frequent rains, are always dreaded by the crew of a sailing ship about to cross the equator. In many instances ships have been

detained in these calm regions for weeks in a state of painful helplessness, the crew being unable to do anything but wait patiently for a breeze to fill their flapping sails. The water all around them resembles a waste sheet of glossy, smooth ice, slowly rising and falling with the monotonous motion of the sea.

Thanks to the efficiency of the Hydrographic Office of the Navy Department, Sailing Directions and Pilot Charts are now issued regularly, showing the best route for sailing vessels to take in different months of the year in order to avoid these calm regions, or at least to cross the belt of doldrums where its extent is smallest. The study of these directions and charts should never be neglected by a navigator about to cross this zone.

21. Table II shows the approximate limits of the trade winds and calm regions during the months of March and September in the Atlantic and Pacific oceans.

TABLE II

LIMITS OF TRADE WINDS AND CALM REGIONS

	Extent in Atlantic Ocean		Extent in Pacific Ocean	
	March	September	March	September
N E trade wind .	26° N— 3° N	35° N—11° N	25° N— 5° N	30° N—10° N
S E trade wind .	1° N—25° S	3° N—25° S	3° N—28° S	7° N—20° S
Doldrums . . .	3° N— 0°	10° N— 3° N	5° N— 3° N	10° N— 7° N

22. Horse Latitudes.—The regions of light, variable winds and occasional calms prevailing at the outside borders of the trade winds, both in north and in south latitudes, are commonly known among mariners as the **horse latitudes.** Unlike the doldrums, these regions are marked for comparatively clear and fresh weather.

23. Regions of Westerly Winds.—Outside the horse latitudes, and all across the temperate zones, westerly winds predominate, although they are frequently interrupted by

WIND CHART

Showing General Direction of Prevailing Winds for January and February

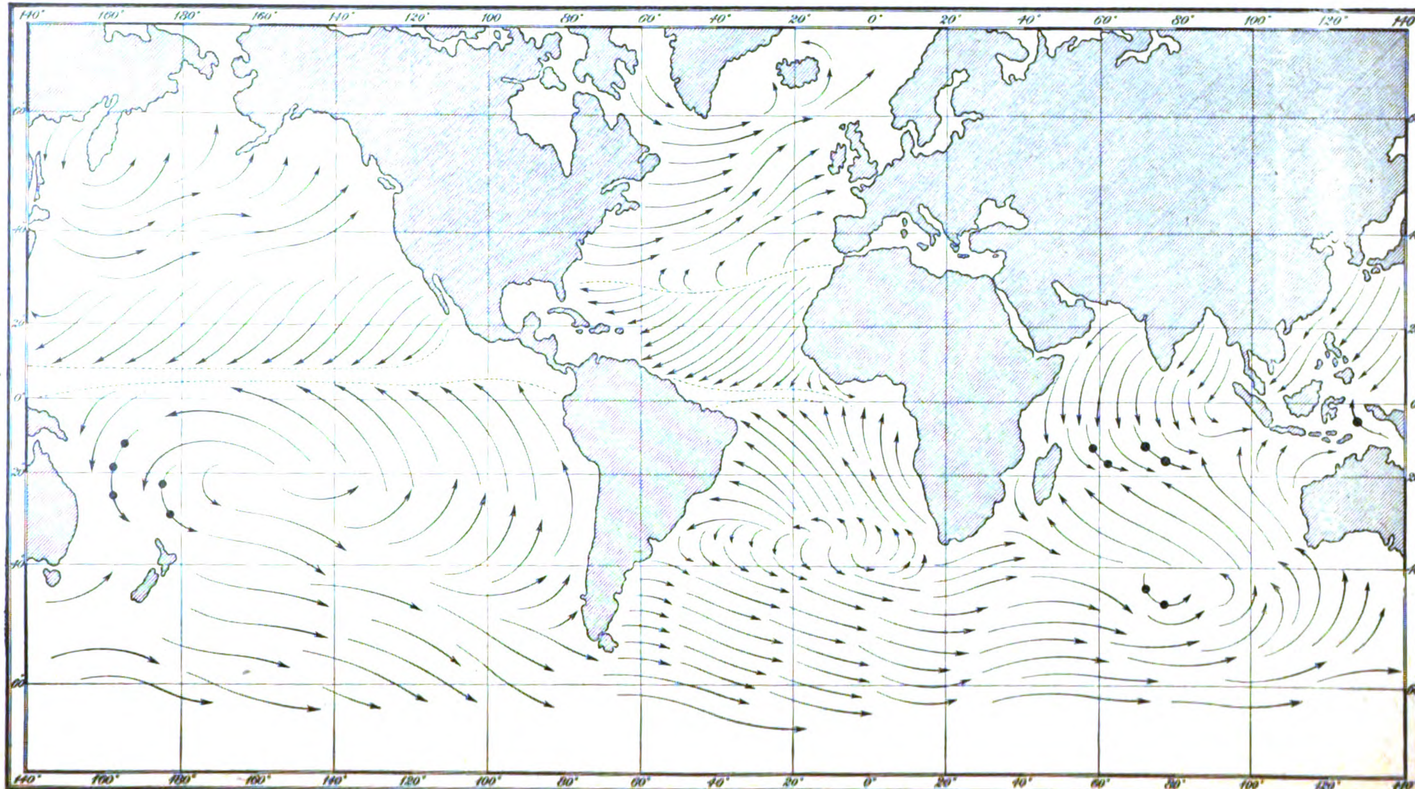

Fig. 9

storms and occasional shiftings. For instance, between 40° and 60° S the wind blows almost continuously from some westerly point. Exceptions, of course, occur; but, taking the average of wind directions in a certain time, say, for instance, a year, the resultant of the several wind components during that period will be westerly. For this reason the passage around Cape Horn to the westward, in a sailing ship, is always considered as a "rough passage," the wind generally being from the west with rainy, cold, and stormy weather. Sailing vessels from Northern Europe and the United States, bound for ports in Australia, New Zealand, etc., therefore take an outward course by Cape of Good Hope, but return across the South Pacific Ocean, passing Cape Horn to the eastward, thus carrying comparatively fair winds nearly all around the world. These westerly winds just mentioned are sometimes termed ***anti-trade winds.***

PERIODICAL WINDS

24. Monsoons.—Of the periodical winds, the **monsoons** are the most noteworthy and important. Like the trade winds, the monsoons are caused by the inequality of heat at different regions as well as by the rotation of the earth. The monsoons of the Indian Ocean and China Sea are the most famous winds of their class. Throughout the whole of this region, as far as 30° N in India and 20° S, between Madagascar and the coast of Australia, the wind is reversed every 6 months. From October to April, the northeast trade wind blows down toward the equator with clear weather. Shortly after entering the southern hemisphere, however, this wind turns to the left (see wind chart, Fig. 9) and changes into the northwest monsoon up to the limits of latitude already mentioned, bringing with it sultry, damp weather and torrents of rain. During the months of April to October the conditions are reversed. The southeast trade wind, after having crossed the equator, turns to the right (see wind chart, Fig. 10) and becomes the southwest monsoon, bringing with it sultry and wet weather. In both

WIND CHART

Showing General Direction of Prevailing Winds for July and August

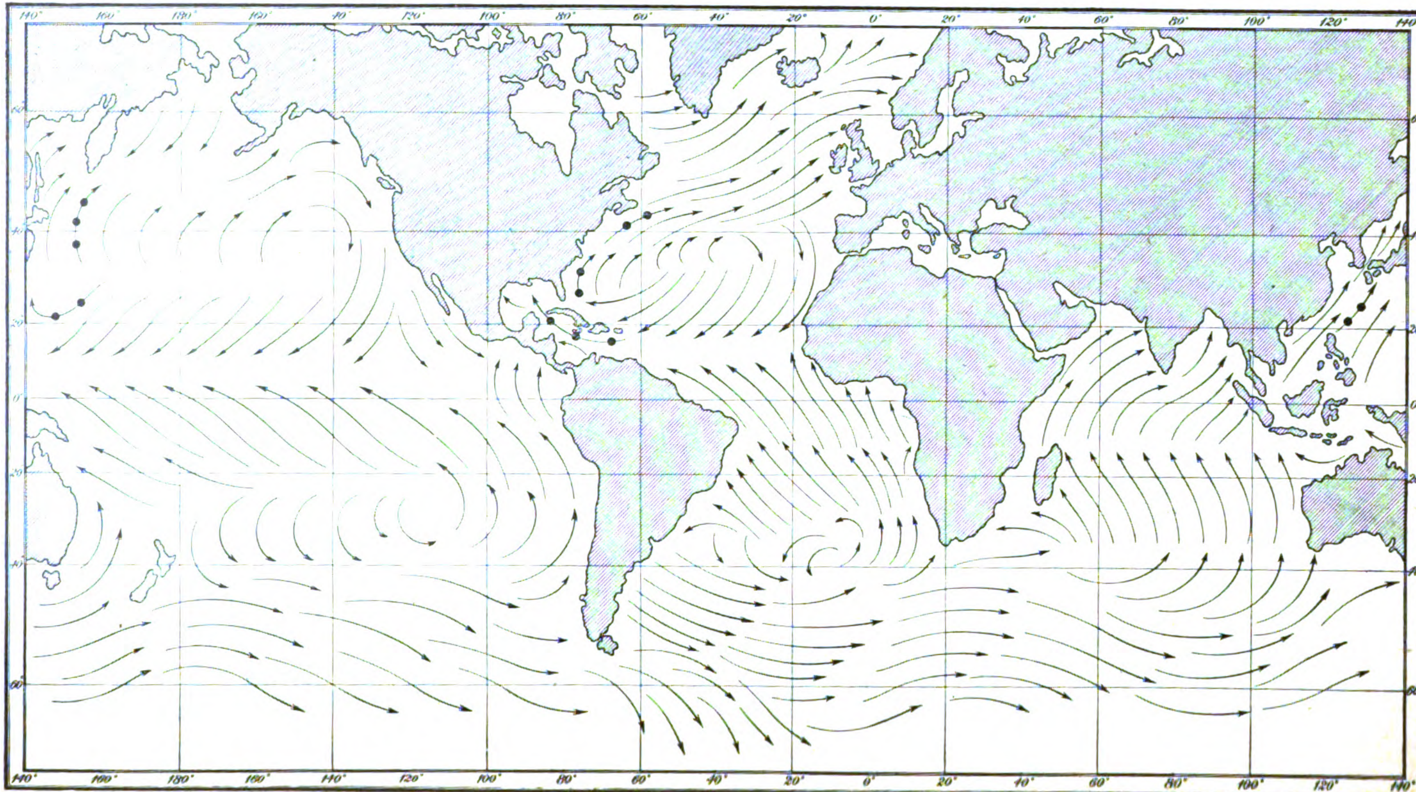

Fig. 10

cases, the wind that brings the rain comes from the equator. The northwest monsoon is also known as the *winter monsoon*, and the southwest monsoon as the *summer monsoon*. The latter is of comparatively greater velocity than the former.

The periods of change of direction of these winds, which occur about April and October, respectively, are called the *breaking of the monsoon*. These changes are always marked by variable winds that alternate between dead calms and furious hurricanes.

25. Wind and Pilot Charts.—On the wind chart, Fig. 9, is represented, by means of arrows, the general direction of prevailing winds during the period of January and February, while in Fig. 10 is represented the predominating wind directions for July and August. The black dots attached to some of the arrows indicate winds of hurricane force. These charts, it should be understood, are intended to serve merely as a general guide. For full and accurate information on this subject, the monthly *Pilot Charts* issued in advance by the United States Hydrographic Office should be consulted. These charts, besides serving as general weather maps, contain a great amount of valuable information for navigators not elsewhere to be found.

LAND AND SEA BREEZES

26. The winds known as **land and sea breezes** are invariably met with along coast lines in the tropics and in the temperate zones. The sea breeze begins in the morning hours and brings in pure, cool air from the sea. Late in the afternoon, after sunset, the land breeze springs up and blows gently out to sea until morning. In the tropics and the temperate zones, this process is repeated in regular order along the shores of such countries as are not directly affected by the trade winds. For instance, on the northeast coast of Brazil, which is constantly swept by the southeast trade winds, the phenomenon of land and sea breezes is not experienced.

27. These diurnal winds are probably caused as follows: During the day the land is heated more rapidly than the sea, and during the night it is more rapidly cooled. In the morning, therefore, the air over and near the land, being heated by the sun, will rise, and colder air from the sea will flow in to supply its place; this produces the sea breeze during the day. During the night and shortly after sunset, the land becomes colder than the sea, and a flow of the cooled air will begin to move seawards to take the place of the warm air over the sea, which warm air then ascends. This movement of air produces the land breeze. To vessels engaged in the coasting trade, these winds are of particular importance.

VARIABLE WINDS

28. The Simoom and Sirocco.—Among the variable winds, or winds that blow without any marked regularity as to time and place, those prevailing on the deserts of Africa and Arabia are perhaps the most remarkable, on account of their extreme dryness and intense heat. In Arabia and on the shores of the Red Sea, this wind is known as the **simoom,** signifying hot, poisonous, or dangerous, while in Upper Egypt it is called the **khamsin.** In Sicily, South Italy, and adjacent districts, it is called the **sirocco,** and is considered poisonous by the inhabitants. However this may be, the simoom through its dryness and impalpable dust exercises an unhealthful influence on the regions through which it passes, and is especially dangerous to those that do not know how to protect themselves.

29. The Puna.—Another wind remarkable for its dryness is the **puna,** a mountain wind of Peru. This wind is a continuation of the trade winds, which, after having crossed the lofty range of the Peruvian Andes, are cooled and parched to an extent that has perhaps no parallel in any other country of the world.

30. The Pampero.—A sister wind of the puna is the **pampero,** which blows from the Andes across the pampas

of the South American Continent toward the Atlantic Coast. This is also a very dry wind, frequently darkening the sky with clouds of dust and sand and drying up the vegetation of the pampas to a considerable extent. The pampero often carries dust and insects hundreds of miles out to sea. To vessels plying on the Rio de la Platà and adjoining rivers, this wind is quite dangerous, on account of its fierceness and its effect on the rise and fall of the water.

31. The Bora.—On the south coast of Europe, north winds are notorious for their violence. Of these winds, the most noted is the **bora,** which means "furious tempest." The bora is greatly dreaded in the upper part of the Gulf of Venice, where annually a number of vessels are sacrificed, and entire districts of the shore are nearly rendered uninhabitable by the destructive effects of this wind on the vegetation. No sign or warning of any kind is given of the approach of the bora, which usually takes place a couple of hours after sunset. The only thing indicating its near presence is a big drop in the atmospheric pressure about a quarter of an hour before the storm comes. The duration of this wind, however, is brief.

32. The Nortes.—Another variable wind that has attained a general reputation, usually owing to the dangers to shipping that its prevalence entails, is the **nortes** (northers) of the Mexican Gulf. This wind is indicated by unusually fine precedent weather, a light bank of clouds in the north, followed, perhaps, by a faint northerly breeze coming in puffs and the barometer always rising. Nortes occur from September to June.

REVOLVING STORMS

33. Revolving storms are known under various local names. In the West. Indies and in southern parts of the United States, they are known as **hurricanes,** while in the Indian Ocean and the China Sea, they are termed **typhoons.** They may, however, be classed under the general term of **cyclones,** owing to the more or less circular direction

of the winds that constitute them. Among the distinctive features by which the revolving storms may be distinguished from an ordinary gale, the following are prominent.

CHARACTERISTIC FEATURES OF A CYCLONE

34. Rotary Motion.—Cyclones have a rotary motion around a center, or focus, and a progressive motion varying from 4 to 15 miles per hour; the latter motion, however, depends to a great extent on local conditions. Thus, the path of a cyclone advancing toward a coast of high land is often changed considerably. The peculiarity of the rotary motion of a cyclone is that in each hemisphere the rotation invariably takes place in different directions. Thus, in the northern hemisphere, the rotation is *contrary* to the motion of the hands of a watch, that is, from right to left; in the southern hemisphere, the rotation is *with* the hands of a watch, that is, from left to right, as shown in Fig. 11.

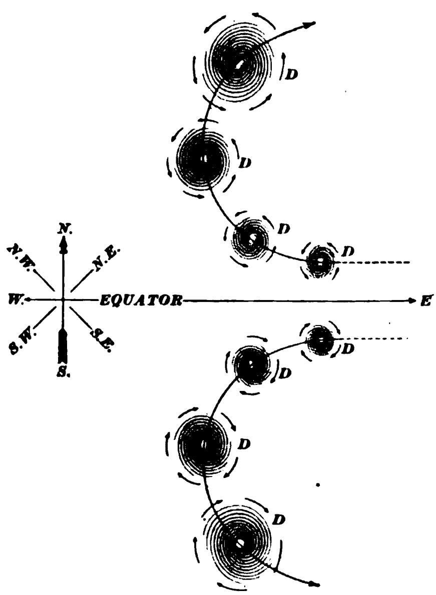

Fig. 11

35. Progressive Motion.—In all cases within the tropics, these revolving storms commence in the east. For some days they travel slowly along a path not exactly west, but inclining a point or two toward the pole of the hemisphere in which they begin. As they advance, they seem to be more inclined to curve away from the equator, and when

reaching the 25th to 30th parallel of latitude, they generally curve still more, at the same time increasing their progressive motion until they move in a northeast direction in the northern hemisphere and in a southeast direction in the southern hemisphere, as shown in Fig. 11.

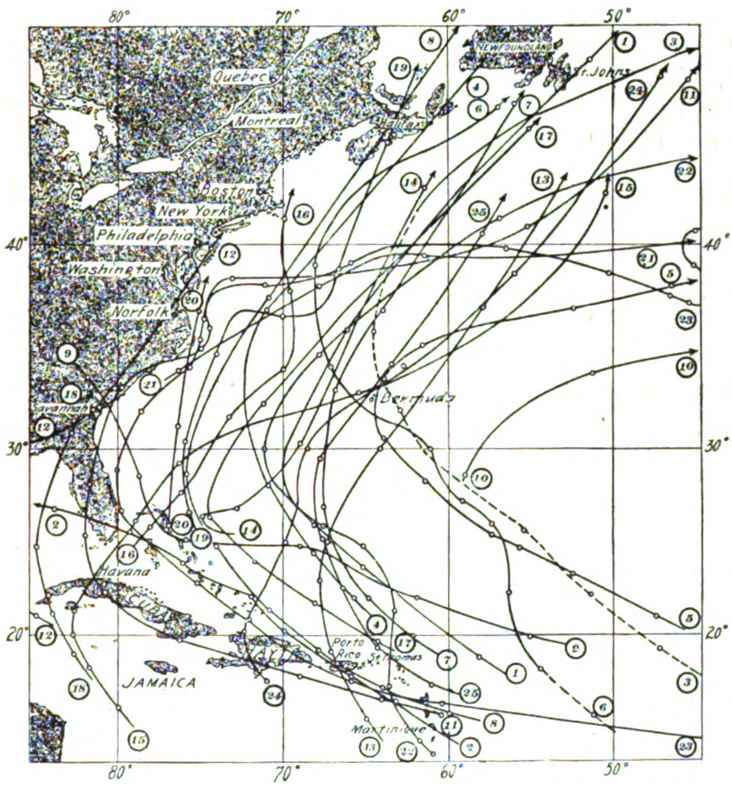

FIG. 12

Some cyclones, however, seldom or never recurve; thus, the cyclones of the Bay of Bengal move, according to the season, either from east to west or from south southeast to north northwest. The typhoons of the China Sea are of both types. Hurricanes have also traversed the northern part of the North Atlantic Ocean from west southwest to east northeast without having recurved, as did the hurricane of October

20 to 23, 1897 (indicated in diagram of Fig. 12, by the curve numbered *21*). Similarly, the progressive motion of cyclones in the Southern Pacific Ocean are sometimes east southeast and southeast, forming areas of low pressure, amalgamating as they pass onward, and then finally dispersing. As previously stated, the progressive motion is governed by local circumstances, but the rate of this motion has no necessary connection with the force of the wind.

The accompanying diagram, Fig. 12, compiled by the United States Hydrographic Office, shows the path followed by the center of each of the tropical cyclonic storms that occurred in the North Atlantic Ocean during the 10-year period 1890 to 1899. The indicated points in each track mark the position of the storm center at Greenwich mean noon of successive days, and the intervals between these points show the distance traversed by the storm center during approximately 24 hours. The dates of the several storms are as follows:

1.	Aug. 27—Sept. 1, 1890	13.	Oct. 12—Oct. 18, 1894
2.	Aug. 19—Aug. 25, 1890	14.	Oct. 24—Oct. 27, 1894
3.	Aug. 19—Aug. 31, 1891	15.	Oct. 18—Oct. 25, 1895
4.	Sept. 4—Sept. 9, 1891	16.	Sept. 5—Sept. 10, 1896
5.	Sept. 16—Sept. 25, 1891	17.	Sept. 19—Sept. 25, 1896
6.	Sept. 28—Oct. 7, 1891	18.	Sept. 26—Sept. 29, 1896
7.	Aug. 17—Aug. 22, 1892	19.	Oct. 9—Oct. 14, 1896
8.	Aug. 15—Aug. 22, 1893	20.	Oct. 23—Oct. 26, 1897
9.	Aug. 23—Aug. 28, 1893	21.	Oct. 20—Oct. 23, 1897
10.	Sept. 6—Sept. 9, 1894	22.	Sept. 11—Sept. 20, 1898
11.	Sept. 20—Oct. 4, 1894	23.	Aug. 3—Aug. 25, 1899
12.	Oct. 5—Oct. 10, 1894	24.	Aug. 30—Sept. 7, 1899

36. Shape, Diameter, and Barometric Pressure. The shape of a cyclone is seldom circular, but rather oval or elliptic, and its diameter, which is generally very small at its origin, expands with the increase in latitude to as much as 800 or 1,000 miles. When the storm area is thus expanded, the destructive character of the storm is lost, and it is then principally engaged in causing heavy rains in its vicinity. It is evident that the barometric pressure of a cyclone is least at the center, where it often is as low as

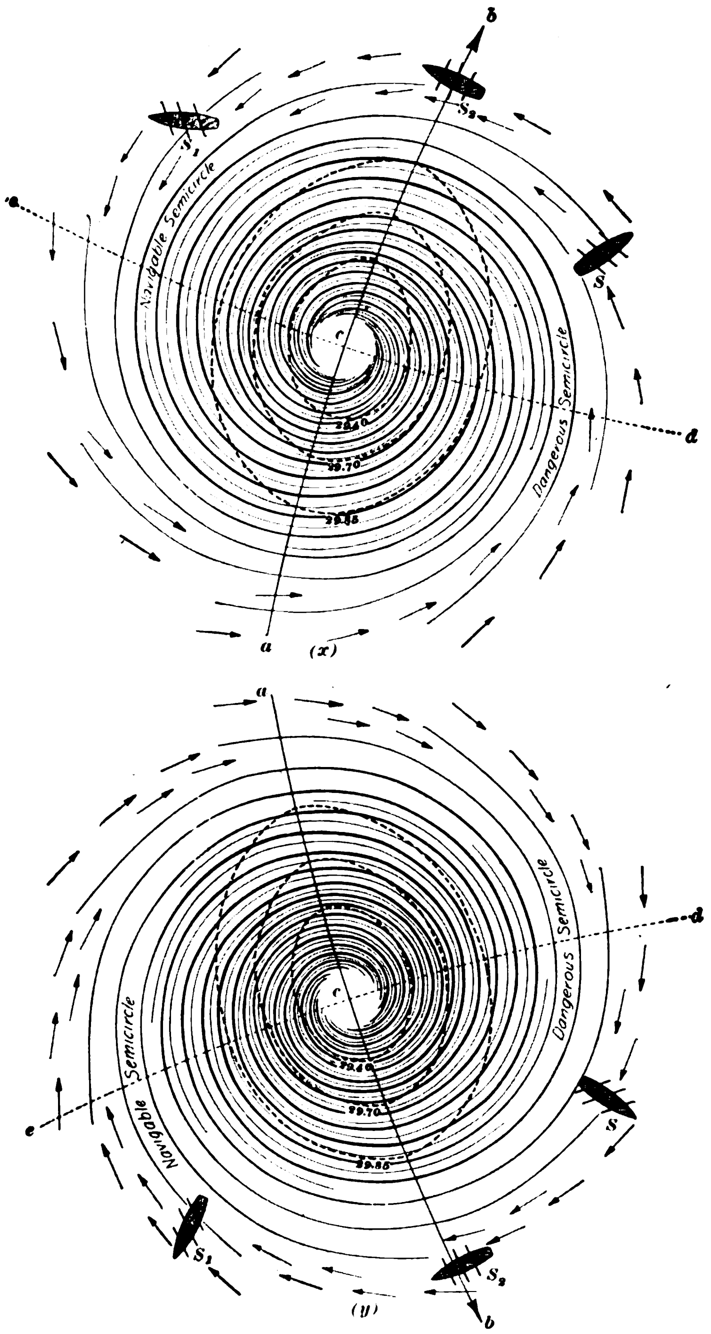
b
S_2
S_1
Navigable Semicircle
S
c
Dangerous Semicircle
29.40
29.70
29.85
d
e
a
(x)
a
Dangerous Semicircle
d
c
Navigable Semicircle
e
29.40
29.70
29.85
S
S_1
S_2
(y)
b

Fig. 13

28 inches or less, and that the pressure is gradually increased toward the circumference of the storm area.

37. Direction of Winds.—The winds within a cyclone do not blow in perfect circles nor in straight lines, but rather in irregular spirals. They blow in a more circular direction on the outside of the cyclone than near its center. A cyclone, therefore, must not be thought of only as a rotating disk propelled mechanically from parallel to parallel, but also as an atmospheric eddy (see Fig. 13) that dies out in its rear but is rapidly renewed in its front.

38. Cyclone-Infested Regions.—Tropical cyclones are never met within the belt between 10° N and 10° S, but outside of these limits they occur in the following regions:

North Atlantic Ocean—Western part, in the vicinity of the West Indies and along the southeast coast of the United States.

South Atlantic Ocean—Southern part.

North Pacific Ocean—The China and Java seas and the coast of Japan.

South Pacific Ocean—Eastern part.

North Indian Ocean—Bay of Bengal and Arabian Sea.

South Indian Ocean—Near Mauritius and Réunion islands.

Cyclones are little known in the South Atlantic and South Pacific oceans. In the latter, they are only occasionally met with in the region east of Australia. In the northern gulfs of the Indian Ocean, particularly in the Bay of Bengal, cyclones occur with dreaded violence.

39. Cyclone Seasons.—Years of diligent observations have established the fact that the most cyclone-infested regions of the globe are the West Indies, the Arabian Sea, and the China Sea. The worst cyclone months in the various regions are given as follows:

West Indies—June to October, particularly August and September.

South Atlantic Ocean—December to February.

Bay of Bengal and Arabian Sea—April, May, October, and November.

South Indian Ocean—January to March.
China and Java seas—July to October.

40. Dangerous and Navigable Semicircles.—From the rotary motion of cyclones, it is evident that the wind in the front and rear must be in a direction perpendicular to the line of progression *a b*, Fig. 13 (x), or nearly so. In other words, if the cyclone is moving in a north north-easterly direction, the wind in its front should be about east southeast, and in its rear about west northwest. From this an important conclusion may be drawn; namely, that if the area of the cyclone is assumed to be divided into two equal parts by the line of progression *a b*, and that another line *e d* is drawn through the center *c* perpendicular to *a b*, the front quadrant *b c d*, in which the wind blows toward the line of progression, or track of center, is the most dangerous part of the cyclone, with the exception of the center itself. The rear quadrant *a c d* may also be considered dangerous, because the direction of the wind will tend to carry the vessel that may happen to be there into the front quadrant and thence into the path of the center. These two quadrants, or the semicircle *a d b*, are therefore known as the **dangerous semicircle**, and the other half *a e b* as the **navigable semicircle**, since the wind in the latter will blow away from in front of the storm center. These semicircles change sides when the hemisphere is changed, the dangerous semicircle always being to the right of the line of progression in northern latitudes and to the left in southern latitudes.

41. From the foregoing, rules have been drawn up for the use of navigators to enable them to determine on which tack a ship should be hove-to when confronted with a storm of cyclonic character. The object of these rules is to insure the wind shifting farther aft so that the ship may be gradually "coming up" and thus prevent her from be "taken aback" in which case she would be in danger of gathering sternboard.

SUGGESTIONS FOR THE HANDLING OF SHIPS IN OR NEAR CYCLONES

42. As to the handling of ships in or near a cyclone, it should be borne in mind that the safety of a vessel will depend to a great extent on good judgment as well as on a knowledge of the nature and peculiarities of revolving storms. All positive rules are, of course, more or less defective, and if blindly carried out may prove dangerous; they are, nevertheless, of great value when judiciously used in combination with a good judgment of prevailing circumstances.

The first thing for a navigator to do when he has good reason to believe that a hurricane is approaching, is to find the bearing of its center and then to shape his course so as to avoid it.

43. Hurricane Signs.—The early indications of an approaching hurricane are generally as follows: Barometer above the normal, with cool, very clear, pleasant weather; a long, low ocean swell from the direction of the distant storm; light, feathery, cirrus clouds, radiating from a point on the horizon where a whitish arc indicates the bearing of the center. Later indications are a falling barometer; halos about the sun and the moon; increasing ocean swell; hot, moist weather with light, variable winds; deep-red and violet tints at dawn and sunset; a heavy mountainous cloud bank on the distant horizon; barometer falling rapidly, with passing rain squalls. The most timely and trusty indication of a cyclone is often the rise of the thermometer in connection with a reversal of the normal wind. Thus, in tropical seas, a brisk westerly wind suddenly springing up should at once arouse suspicion, particularly in the hurricane season. Equally suspicious is a strong easterly wind suddenly succeeding the normal westerly winds prevailing between 40° and 45° N on the routes between the United States and Europe. Scarcely anything, except an approaching area of low atmospheric pressure, can be supposed to cause the sudden change of the East Indian monsoon in August and

September. A cautious navigator, therefore, may, by attending to the abnormal and sudden change of wind direction, foresee that he is in front of a revolving gale, though his barometer remains high, the sea smooth, and none of the usual signs of hurricanes can be distinguished overhead.

44. To Find Bearing of Storm Center.—Being convinced that the approaching storm is of a cyclonic character, the bearing of its center should be determined. This is done by facing the wind, in which position the center may be assumed to bear 10 or 11 points to the observer's right in northern latitudes, and 10 or 11 points to the left in southern latitudes. If, however, the ship is well within the storm area, and the barometer is falling steadily, the bearing of the center may be less than 10 points; and if the barometer has fallen as much as $\frac{1}{2}$ inch, the bearing may be considered as 8 points.

45. To Determine Position of Ship in Relation to Storm Track.—Having the approximate bearing of the storm center, the next thing to do is to find the position of the ship in relation to the track, or line of progression, of the storm. This can be determined by observing the shifting, or veering, of the wind. In the northern hemisphere, if the wind shifts to the right, the ship is to the right of the track, as at S, Fig. 13 (x), or in the dangerous semicircle; if it shifts to the left, the ship is to the left of the track, as at S_1, or in the navigable semicircle.

These conditions are reversed in the southern hemisphere. There, if the wind shifts to the right, the ship is to the right of the track, as at S_1, Fig. 13 (y), or in the navigable semicircle; while, if the wind shifts to the left, the ship is at S, or in the dangerous semicircle (in both cases the observer is assumed to be looking in the direction *toward which the storm is advancing*). But if the wind is "steady," shifting but very slightly and increasing in velocity, it indicates that the ship, whether in the northern or in the southern hemisphere, is on the track and in front of the center, as at S_2, Fig. 13 (x) and (y).

46. To Find Whether Center Is Approaching or Receding.—When a ship is well within the area of a hurricane, the approach of the center is indicated by a rapidly falling barometer, increase of wind, heavy squalls, intense lightning and rain, heavy and confused sea, continued shifting of the wind, except when on the track of the center.

The receding of the center is usually indicated by a rising barometer, more steady wind decreasing in velocity, weather clearing, but sea very confused and dangerous.

47. Brief Rules for Action to Avoid Center.—Having determined the bearing of the storm center and the position of the ship in reference to the progressive motion of the storm, the following rules for avoiding the storm center should be adhered to so far as circumstances will permit:

Northern Hemisphere.—If on the track of the storm center and in front of the advancing storm, run or steam before the wind; keep a steady course until the wind shifts well on starboard quarter. Then, if obliged to lie-to, do so on the port tack.

If in the dangerous semicircle, steam or run off with the wind on starboard quarter; if obliged to lie-to, do so on the starboard tack.

If in the navigable semicircle, steam or run off with the wind on starboard quarter; if obliged to lie-to, do so on the port tack.

Southern Hemisphere.—If directly in front of the advancing storm center, run or steam before the wind; keep a steady course until the wind gradually shifts around to the port quarter. Then, if obliged to lie-to, do so on the starboard tack.

If in the dangerous semicircle, steam or run off with the wind on the port quarter; if obliged to lie-to, do so on the port tack.

If in the navigable semicircle, steam or run off with the wind on the port quarter; if obliged to lie-to, do so on the starboard tack.

Vessels, especially steamships, sometimes overtake hurricanes because their speed is greater than the progression of the storm center. In such cases, it is obvious that the ship's course should be altered so as not to approach the center.

48. Storm Center.—The foregoing rules apply to cases when hurricanes are encountered in open sea. If, however, the vessel is unable, from want of sea room, to perform the necessary maneuvers, her position may become one of serious concern. Every precaution should then be taken to prepare for the passage of the storm center over the ship. In entering the center, which may be several miles in diameter, the wind suddenly ceases and glimpses of clear sky can be seen, now and then interrupted by puffy squalls. The sea is enormous and very dangerous, apparently coming from all directions of the compass. After the center has passed over, the ship is again struck by a gale of renewed energy and hurricane force, but from the opposite direction. This constitutes one of the most critical dangers known to seamen. Apparently, the best thing to do when caught in the center of a hurricane is to try to get the vessel in such a position as to best meet the opposite wind, which may be expected to burst forth very quickly and violently, and thereby prevent the ship from gathering sternboard, or drifting backwards in a helpless position with enormous seas breaking over her. Only strongly built vessels are able to withstand the heavy strain they are subjected to on such occasions, and many ships whose names now figure on the list of "missing" in all probability met their fate in the center of a revolving storm.

49. The Typhoon.—The typhoon of the Western Pacific Ocean is, in many respects, the counterpart of the West Indian hurricane of the Atlantic. Both classes of storms have their origin in the vicinity of tropical groups of islands and under similar barometric conditions; both undergo the same slow development and exhibit a similar tendency to recurve on reaching the higher latitudes.

The first barometric indication of the approach of a typhoon is the disturbance of the daily fluctuations of the mercurial column. In the low latitudes where typhoons originate, a good mercurial barometer during settled weather should show a decided maximum about 10 A. M., the reading at that hour standing between 29.85 and 29.95 inches (758.2 to 760.7 millimeters), while about 4 P. M. there should be a corresponding minimum, the reading at that hour being about $\frac{1}{10}$ inch (2.5 millimeters) less than at 10 A. M. The same thing is repeated at 10 P. M. and at 4 A. M. If the forenoon maximum is appreciably below 29.85 inches, or if the descent between this and the afternoon minimum is markedly greater than $\frac{1}{10}$ inch, the weather should be watched with great care. Several successive days of light, variable winds and calms; a period of hot, sultry weather; increasing moisture of the atmosphere, increasing amount of cloud, and an ominous heaving of the sea, are all conditions forerunning the occurrence of the typhoon.

The average tracks of the various classes of typhoons, together with the frequency and the season of appearance of each class, are to be found on Pilot Charts of the Pacific Ocean. For a more complete account of typhoons, consult the North Pacific Pilot Chart for July, 1898.

50. Remarks About Cyclones.—It must be borne in mind that although the region and season of the year would render the navigator very cautious, yet every strong wind or gale met with, particularly in the tropical regions, should not be treated as a cyclone. When there is reason to suspect the advance of a cyclonic storm, the safest procedure is to lie-to and carefully watch the barometer, weather indications, and shiftings of the wind. A decided drop of the atmospheric pressure of at least $\frac{1}{2}$ inch, together with marked shiftings of the wind, should be experienced before the storm can be concluded as cyclonic.

Whenever hurricane warnings are displayed by the Weather-Bureau stations along coast lines, smaller vessels do well to seek shelter or remain in harbor until the storm

has passed. Vessels under way and capable of weathering the storm should keep at a safe distance off shore, in order to have sufficient sea room in which to carry out the necessary maneuvers indicated in the foregoing rules.

NOTES ON THE WEATHER

51. Weather Indications by a Mercurial Barometer.—The use of the barometer as a weather glass is common both on sea and on land. But only those that have long watched and carefully compared its indications with the prevailing weather conditions are able to foretell more than that a rising barometer indicates less wind or rain; a falling barometer, more wind or rain, or both; a high barometer, fine weather; and a low one, the reverse. But useful as are these general conclusions, in most cases, they are sometimes erroneous. By attending to the following brief observations, any one not accustomed to the use of a barometer may do so with less hesitation and with immediate advantage.

52. The column of mercury in a good barometer usually stands, on an average, some tenths of an inch higher with or before polar and easterly winds than it does with or before equatorial and westerly winds (of equal strength and dryness or moisture) in all parts of the oceans. The terms *polar* and *equatorial* are here used with reference to winds blowing from the nearest polar direction, or from the equatorial parts of the earth.

This peculiarity of the barometer causes many mistakes to be made. The barometer is high, perhaps, but falling. Wind or rain, or both, are expected in consequence, yet neither follows to any decided extent. A change of wind, only, from one quarter to another takes place. Reversely, the barometer is low, but rising. Fine weather is expected; yet, instead of that, a strong wind, accompanied perhaps by rain, hail, or snow, rises from the polar direction. By such changes as these, seamen are often misled, and calamity,

caused by unpreparedness, may sometimes occur as a consequence. There may be heavy rains or violent winds beyond the horizon, and even within the view of an observer, by which his instruments may be affected considerably, though no particular change of weather occurs in his immediate locality. Sometimes, severe weather from an equatorial (southerly in north latitude, northerly in the southern hemisphere) direction, of short duration, may cause no great fall of the barometer, because followed by a duration of wind from polar regions; and at times the mercurial column may fall considerably with polar winds and fine weather, apparently against the rule, because a continuance of equatorial winds is about to follow. Knowledge of these peculiarities of the barometer are particularly useful to the navigator.

53. As a general rule, the barometer *rises* for northerly winds (included between the northwest and northeast), for dry or less wet weather, for less wind, or for more than one of these changes, except on a few occasions, when rain, hail, or snow, with strong wind, comes from the northward.

The barometer *falls* for southerly winds (included between the southeast and southwest), for wet weather, for stronger wind, or for more than one of these changes, except on a few occasions, when moderate wind with rain or snow comes from the northward.

There is little variation of the barometer between the tropics, because the wind generally blows in the same direction and with constant force, and no contending currents of air cause any considerable change in the temperature or density of the atmosphere. For violent storms or hurricanes, however, within the tropics, the barometer falls very low, but soon returns to its usual state after the storm center has passed.

It has been observed on some coasts that the barometer is differently affected by the wind, according as it blows from the sea or from the land, the mercury rising on the approach of the sea breeze and falling previously to the setting in of the land breeze.

54. Indications by Appearance of Sky.—The following rules about weather are worth remembering: a red sky at sunset presages fine weather; a red sky in the morning bad weather or much wind, if not rain; a gray sky in the morning, fine weather; soft-looking or delicate clouds foretell fine weather, with moderate or light breezes; hard-edged, oily-looking clouds, wind; a dark, gloomy blue sky indicates wind, but a light, bright-blue sky indicates fine weather. Generally, the softer the clouds look the less wind, although rain may be expected; and the harder, more "greasy," rolled, tufted, or ragged, the stronger the wind will prove. Also, a bright-yellow sky at sunset presages wind; a pale yellow, wet; and by the preponderance of red, yellow, or gray tints, the coming weather may be foretold very nearly—indeed, if aided by instruments, almost accurately.

These indications of weather, afforded by the colors of the sky, seem to deserve more critical study than has yet been given to the subject.

55. Indications by the Aneroid Barometer.—A rapid rise indicates unsettled weather.

A gradual rise indicates settled weather.

A rise, with dry air and cold increasing, in summer, indicates wind from the northward in north latitudes, but from the southward in south latitudes; and if rain has fallen, better weather may be expected.

A rise, with moist air and a low temperature, indicates wind and rain from the northward in north latitudes, but from the southward in south latitudes.

A rise, with southerly winds, indicates fine weather in north latitudes, and wind with rain in south latitudes.

A steady barometer, with dry and seasonable temperature, indicates a continuance of very fine weather.

A rapid fall indicates stormy weather.

A rapid fall, with westerly winds, indicates stormy weather from the northward.

A fall, with a northerly wind, indicates stormy weather, with rain in summer and snow in winter.

A fall, with increased moisture in the air and the temperature rising, indicates wind and rain from the southward.

A fall, with dry air and cold increasing, in winter, indicates snow.

A fall, after very calm and warm weather, indicates rain with squally weather.

All indications pertaining to the fall of the aneroid apply to northern latitudes; in southern latitudes, wind directions are reversed.

METEOROLOGICAL OBSERVATIONS AT SEA

56. Information for Observers.—The United States Hydrographic Office is conducting an extensive system of ocean meteorological observations. It seeks the coöperation of all navigators, requesting them to take one observation every day at a prescribed moment, which is simultaneous for every part of the globe. These simultaneous observations are charted and published by the Hydrographic Office at Washington on its Monthly Pilot Charts and Hydrographic Bulletins. By entering into this arrangement and taking part in the observational work, every seaman may contribute materially to this scientific enterprise and further the elucidation of the law of storms, as well as secure for his own use a large supply of valuable meteorological information.

When about to sail, the master or navigating officer of a vessel should call at the local branch hydrographic office and request the officer in charge to furnish him with the latest information in the shape of Lists of Lights, Lists of Beacons, Buoys, and Daymarks, Notices to Mariners, Hydrographic Bulletins, and Pilot Charts. All these publications are furnished free to masters that can satisfactorily show that they are voluntary weather observers for the United States Hydrographic Office, or that they are willing to become such. The master should also request a supply of blank weather reports and envelopes sufficient to last until his return to a United States port; also cards for barometer comparisons and instructions as to the manner of

making these comparisons, which are given in Hydrographic Office publication No. 119. The comparison cards should be filled out while the vessel is lying in port and should be mailed before sailing. These cards require (if mailed in a United States port) neither envelope nor postage.

57. For the convenience of those masters who rarely visit an American port, a limited supply of blanks, pilot charts, etc. is maintained at the United States consulate in each of the more important shipping centers abroad. A list of those consulates at which this is the case is published on the monthly pilot charts. The ship having arrived at her destination, the forms containing the observations recorded during the voyage should be enclosed in one or more of the envelopes furnished for that purpose. If in a foreign port, this envelope should be addressed to the United States Hydrographic Office, Navy Department, Washington, D. C., and handed to the United States Consul, who is under instructions from the Secretary of State to forward these reports with his official mail, free of all expense. If mailed in a foreign port, postage must be prepaid.

In any United States port, the package should be addressed to the nearest branch hydrographic office and mailed. The franked envelope does not require any postage when mailed within the United States, Hawaii, the Philippine Islands, or Porto Rico. The forms should be returned promptly at the first port of call. They should not be held until the return of the vessel to the United States.

On the receipt of the completed forms, either at the Hydrographic Office or at any of its branches, a letter of acknowledgment is at once addressed to the master of the vessel, thanking him and the officer charged with the duty of taking the observations for their services, and replying to any inquiry or request that the master or the observer may have made. These letters should be preserved, as they may prove of value in identifying the bearer as an observer at the several branch hydrographic offices, and as such entitled to the various official publications.

OCEAN CURRENTS

PRINCIPAL CURRENTS OF THE WORLD

58. Classification of Currents.—Ocean currents may be conveniently divided into two classes; namely, *drift*, or *surface, currents* and *stream currents*.

59. Drift, or surface, currents are produced directly by the wind, and move along the surface of the water only, in a direction more or less parallel to the wind. Drift currents, therefore, are shallow and slow, and can run in no other direction than before the wind that produces them. The following extract from a publication by the United States Hydrographic Office, relating to drift currents, will no doubt prove very instructive:

"For our knowledge of the surface currents of the ocean as they actually exist, we are dependent largely on ships' observations, and concerning these it may be said that, strictly taken, they represent not the actual current experienced during the preceding 24 hours, but only the difference between the position of the vessel as determined by astronomical observation and as determined by dead reckoning. This difference is made up primarily of the current actually encountered, secondly by the errors in the dead reckoning, arising from incorrectly estimated course and distance—here the deviation of the compass, often poorly determined, plays a most important part—and finally of errors in the astronomical determination of position. Where, however, we have a large number of observations at our disposal, distributed over a small area, it is customary to consider that these errors, made sometimes in one direction, sometimes in another, compensate each other, and that by taking the mean, a truthful estimate of the force and direction of the

current may be obtained. The current charts of any locality, based as they are on the mean of all the observations, aim to present these most frequent conditions, or, in other words, the conditions that are most likely to prevail.

"The irregularities in the currents stand in close relation with the causes producing them, first among these being the winds. A perfectly steady wind, acting continuously on the surface of the sea, will, through friction, give rise to a movement of the surface waters in the same direction as the wind itself. If the latter continues for a sufficient length of time, the impulse, first felt only at the surface, will gradually communicate itself downward, owing to the viscosity of the water, and the lower strata to a successively greater and greater depth will thus partake of the movement until it is finally shared by the whole mass, the velocity of the motion diminishing as the depth increases. The rate, however, at which this motion is communicated to the depths of the ocean is exceedingly slow. It has, for instance, been estimated that in a depth of 2,000 fathoms a surface current of given velocity would require a period of 200,000 years to transmit its due proportion of this velocity to a point half way toward the bottom. Similarly, when once established these submarine currents exhibit a corresponding reluctance to undergo any variation in direction or intensity."

60. Stream currents are produced when a drift current is deflected by meeting an obstacle, such as a line of coast, and flows in a direction imparted to it by the obstacle. A stream current has depth, and in many cases becomes more powerful than the drift current, sometimes assuming such dimensions as to be named "oceanic rivers." These oceanic rivers, for instance the Gulf Stream, may vary in breadth from 50 to 250 miles, and are sufficiently deep to be turned aside by banks that do not rise within 60 or 80 fathoms of the surface.

61. The methods of estimating the drift and rate of a current by means of dead reckoning were described in *Dead*

CHART SHOWING THE PRINCIPAL OCEANIC CURRENTS

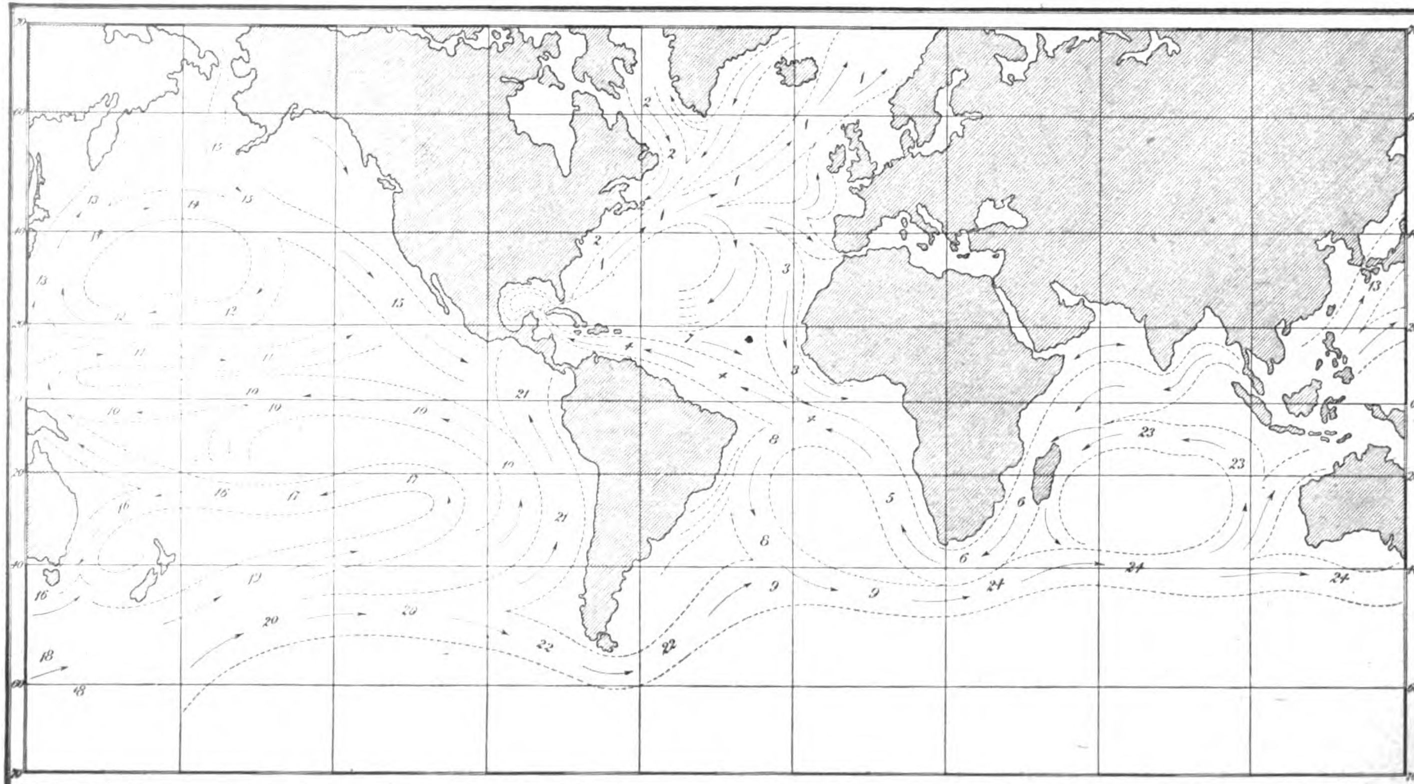

FIG. 14

Reckoning, Part 2. The following articles will therefore be confined to a brief description of the principal currents of the world. When studying this subject, the current chart, Fig. 14, should be consulted. On this chart corresponding numbers denote the same current.

CURRENTS OF THE ATLANTIC OCEAN

62. Gulf Stream.—The principal current of the Atlantic Ocean, and perhaps the most remarkable of the oceanic rivers, is the **Gulf Stream** (denoted on the chart, Fig. 14, by *1*). This current commences in the Gulf of Mexico, and after passing through the Florida Strait takes a northeasterly direction, becoming wider and wider the farther north it advances, and finally terminates between the northern coast of Norway and the Spitzbergen Islands.

Color and Temperature.—The waters of the Gulf Stream are generally intense blue in color, and the junction with ordinary sea-water is distinctly marked. In moderate weather, the edges are marked, also, by ripplings, and in the higher latitudes, frequently by evaporation. The Gulf Stream is essentially a current of warm water. On issuing from the Gulf of Mexico, its maximum temperature is about 85° F., or from 5° to 6° above the ocean temperature, due to that latitude; as it moves on, it loses much of this high temperature, and off the Banks of Newfoundland its temperature becomes from 20° to 30° higher than the adjoining ocean. Various estimates of the average temperature of this current at different latitudes have been made, and among them the temperatures given in Table III may be considered as being fairly accurate.

The contrast of temperature between the Gulf Stream and the Arctic current *2*, which runs between it and the American Coast, is so great that sometimes in passing from one current into another a difference of from 25° to 30° at the surface has been recorded within a cable's length. For this reason, the line of separation between the two currents has been termed the "cold wall," it being a perfectly distinct

line owing to the change of color of the two masses of water. Since observations have proved the Gulf Stream to be a superficial current on the surface of an ocean of cold water, the temperature of its water should be taken at a depth of from 10 to 15 fathoms, special thermometers attached to a lead line being used for this purpose. The temperature taken of the surface water, for instance, by pulling up a bucketful, placing it on deck, and plunging a thermometer into it, cannot always be relied on as representing the actual temperature of the current, since this surface water is necessarily influenced by the prevailing state of weather.

TABLE III

TEMPERATURE OF GULF STREAM

Place	April	June	July	October
Florida Strait	77°	78°	83°	82°
Off Charleston	75°	77°	82°	81°
Off Cape Hatteras	72°	73°	80°	76°
Southeast of Nantucket Shoals	67°	88°	80°	72°
South of Nova Scotia	62°	67°	78°	69°

Velocity.—The velocity and rate of the Gulf Stream varies with the seasons, running strongest in July, August, and September. On entering Florida Strait, the rate is from 2½ to 4 miles an hour; in the narrowest part of the Strait, 5 miles an hour has been observed in August; beyond this to the parallel of 35° N, the rate is about 3½ miles, gradually decreasing as the stream expands to the northward, although even near the meridian of 45° W on the 43d parallel of latitude, the exceptional rate of 4 miles an hour in the month of August has been recorded. Eastward of 35° W, its depth becomes less and less and its rate diminishes accordingly.

63. Arctic Current.—The **Arctic, or Labrador, current** 2, which commences in Baffin Bay, passes through Davis's Strait and skirts the coast of Labrador; then rounding Newfoundland, it proceeds in a southwesterly direction past

Nova Scotia and the coast of the United States, inside the Gulf Stream. The water of this current is very cold, bringing with it large quantities of pack ice and icebergs, which it discharges into the Atlantic Ocean. A branch of the Arctic current runs in a southerly direction down along the east coast of Greenland and effects a junction with the main current in Davis's Strait.

64. Guinea Current.—The **Guinea current** *3* is a drift current setting to the southward along the west coast of Africa. After passing the Cape Verde Islands, it becomes a stream current, running eastward into the Gulf of Guinea. The greatest velocity of this current is stated to be off Cape Palmas, where, at a few miles from the shore, it has been found to run more than 3 miles an hour. For about 200 miles from the coast, between Cape Verde and Sierra Leone, winds and currents change with seasons. From June to September, squally southwest winds with a northeast current prevail; while from October to May, northerly winds and southeasterly currents are experienced.

65. Equatorial Currents.—The **equatorial current** *4* is a vast drift current caused by the trade winds. This current commences near the southwest coast of Africa, where it is known as the **South African current** *5*, which, again, is a continuation of the **Agulhas current** *6*, generated by the great drifts of the Indian Ocean. Between the months of July and November, the northern edge of the equatorial current, in latitude 8° to 10° N, appears to change its direction to northeast and finally settles to the eastward toward the African Coast. This current, whose rate and width increases as it advances eastward, is called the **equatorial counter current** *7*.

66. Brazilian Current.—The **Brazilian current** *8* is a branch of the equatorial current, and runs along the coast of the South American Continent as far as the Island of Trinidad and Martin Vas Rocks, where it divides. One branch of this current runs to the southeast, where a junction with the **southern connecting current** *9* is effected; the

other branch flows in a southwesterly direction along the coast of Uruguay and Argentine Republic, gradually losing in velocity and finally disappearing at about latitude 45° S. This current is, however, greatly affected by prevailing winds.

CURRENTS OF THE PACIFIC OCEAN

67. Equatorial Current.—Among the currents of the Pacific Ocean, the **equatorial current** *10* is the principal one; it sets to the west across the Pacific Ocean at a variable rate, the mean of which is estimated to be about 20 to 24 miles a day. A **counter current** *11* has been proved to exist, setting to the eastward at some distance to the north of the equator, particularly in the western part of the Pacific.

68. The Kuro-Shiwo, or Japan Stream.—To the north of the counter current just mentioned is found the **northern equatorial current** *12*, which sets in the same direction as the mean equatorial; this current is caused by the northeast trade winds. On reaching the eastern shores of the Philippine Islands, the equatorial current is deflected to the northward, forming in latitude 20° N, between the meridian of 125° E and the east coast of Formosa, the commencement of the great oceanic warm current known as the **Kuro-Shiwo,** or **Japan Stream** *13*, the limits and rate of which are greatly influenced by the monsoons of the China Sea and the prevailing winds in the Yellow and Japan seas. The changes in direction of this current due to monsoons, etc. should be carefully studied in Sailing Directions and Pilot Charts by those expecting to navigate in these localities.

69. North Pacific Drift Current. — The **North Pacific drift current** *14*, which is a branch of the Japan stream, crosses the Pacific Ocean in a general easterly direction. At about latitude 40° N and longitude 150° W, it changes into a southerly direction, joining the north equatorial current near the Sandwich Islands.

70. Arctic Current.—The **Arctic current** *15*, which flows from Bering Strait in the direction of the North American continent and terminates on the Mexican coast, is not of the same magnitude and importance as the Arctic current of the Atlantic Ocean; its mean velocity is estimated to be about $\frac{7}{10}$ mile per hour, and usually the current is stronger near the land than at sea.

The direction and velocity of currents in the upper part of the North Pacific Ocean are, however, little known, owing to the meager reports available from that region. The Hydrographic Office on its Pilot Chart of the North Pacific Ocean (August, 1901) prints the following notice in reference to this region: "After a careful consideration of the reports of vessels cruising near the Aleutian Islands and Bering Sea, the Hydrographic Office warns mariners against placing too much reliance upon current predictions in that portion of the North Pacific."

71. Other Important Pacific Currents.—The **Australian Ocean current** *16*, which is a branch of the **southern equatorial current** *17*, sets along the east coast of Australia. The greater part of this current makes its way to the coast of New South Wales, where it meets and is reversed by the **Antarctic current** *18*, issuing from Bass Strait.

To the south of New Zealand are found strong easterly drift currents *19*, *20* that are produced by the prevailing westerly winds. After reaching the South American Coast, one branch of these drift currents turns toward the north and runs along the coast of Peru, being known, then, as the **Peruvian current** *21*. The other branch turns into an east-by-southeast direction and forms the **Cape Horn current** *22*, which, after passing around Terra del Fuego, turns into a northeasterly direction and is absorbed by the southern connecting current *9*.

CURRENTS OF THE INDIAN OCEAN

72. In the Indian Ocean, the motion of the water north of the equator is entirely regulated by the winds. From October to April, when the northeast monsoon blows, the current runs to the westward, around the shores of the Arabian Gulf; from April to October, when the southwest monsoon prevails, the water flows in exactly the opposite direction. The great **westerly equatorial drift current** *23* of this ocean lies to the south of the equator, and flows on until it impinges on the African Coast, where it splits into two streams. One of these turns to the south, running along the coast of Madagascar, and is finally absorbed by the **easterly drift current** *24*, which passes south of the Australian Coast and eventually finds its way into the Pacific Ocean. The other branch of the equatorial drift current turns southward along the Mozambique Channel, and after passing the latitude of Durban, is known as the Agulhas current *6*. This current is essentially a body of warm water with an occasional velocity of 4 miles an hour.

NOTE.—The foregoing brief description of the principal currents of the world will serve merely as a general guide. For particulars as to the direction and velocity of the currents at certain localities, during certain months, Sailing Directions and Pilot Charts should be consulted and studied.

TIDES AND TIDAL CURRENTS

GENERAL THEORY OF TIDES

73. As previously stated, the **tide** is the alternate rise and fall of the water in the ocean, as seen on sea beaches, cliffs, estuaries, etc. When the water rises to the highest point it is capable of reaching on any particular day, it is called *high water*, or *high tide;* when it sinks to the lowest possible ebb, *low water* or *low tide* is reached. Generally, high tides follow each other at intervals of 12 hours and 25 minutes; low tides succeed each other at the same interval.

74. Cause of Tides.—The most potent cause in producing the tides is the moon. It is obvious that by the laws of gravitation the moon must attract the water of the ocean on the particular side on which she is at the time, and if the earth were immovably fixed, and there were no sun, this would be all. But the earth is not fixed, and in addition to drawing the water to her from the earth on one side of the globe, the moon draws the globe itself away from the water on the other side, thus making high water at the same time on opposite sides of the earth.

The sun also exerts an attraction, but, owing to its great distance, the mean force of the sun in raising the tide is to that of the moon only as 1 is to 2½; for though the mass of the sun is vastly greater than that of the moon, the distance of the sun causes it to attract different parts of the earth with nearly the same force. When the sun and moon exert their influence in one direction, the tide produced is greater than when they counteract each other's attraction. Though to an observer on land the water seems to rise and fall alternately, yet what really takes place on the ocean at large is that the moon raises a wave, which follows her movement,

thus producing high water in regular succession as the earth turns on its axis. If the earth did not revolve, tides would only occur every 14 days.

The energy producing tides is, thus, mainly of the earth, not of the moon; the store of earthly energy is therefore reduced by the tides, which act as a brake, or drag, on the revolving globe, while the energy of the moon is increased by them. The effect is to retard the rotation of the earth and to cause the moon to increase her distance from the earth slowly.

75. Tides reaching the shore are affected by its conformation. Thus, in a nearly enclosed sea like the Mediterranean, tides are only from 1 to 3 feet high. Far out in the ocean they have but a small range; thus, at St. Helena they are only 3 feet, while at London they are 18 or 19 feet. At Cardiff, the greatest tides are from 37 to 38 feet and the lowest from 28 to 29 feet; the greatest tide, that in the Bay of Fundy, is 50 feet.

To the definitions of terms relating to tides given in *Elements of Navigation* the following supplementary explanations are appended.

76. Lunitidal Interval.—The interval between the moon's meridian passage and the next high water under that meridian is called the **lunitidal interval**, and its daily variations are caused by the priming and lagging of the tides. The lunitidal interval at any port on the days of new and full moon is called the *common*, or *vulgar*, *establishment of the port*, and this is indicated in the tidal data of charts by the letters H. W., F., and C. (High Water, Full, and Change).

The mean of all the lunitidal intervals of a lunar month (28 days) is called the *corrected establishment of the port*, and this should be used in preference to the vulgar establishment when finding the time of high water. The common, or vulgar, establishment may be an hour or more in error when used as representing the H. W. on *any* day of the month.

77. Plane of Reference.—The plane of reference as given on charts is the level of the sea at *mean low water*, or the mean of all the low waters of a lunar month. It will be seen that there is never less water at any point than is shown by soundings, except at spring tides. The difference between the lowest tide and the plane of reference is usually found on charts under the heading Fall of Lowest Tide Observed Below the Plane of Reference.

78. Diurnal Inequality.—The maximum of the daily inequality corresponds with the moon's greatest declination, though it may not appear until after the time of the moon's greatest declination (N or S). In a like manner, it disappears with the moon's declination (0°), but may not be manifest until after she has crossed the equator.

In consequence of the diurnal inequality, it sometimes happens that the day tides are higher than the night tides, or the reverse, for many weeks together. The rule of the diurnal inequality depends on the declination of the moon and the sun. If the day tides are highest at one time of the year, they are the lowest at another.

79. Effect of Atmospheric Pressure on the Tides. The pressure of the atmosphere affects the height of the tide to a certain degree, the water generally being high when the barometer is low.

80. Effect of Winds on the Tides.—Strong winds affect the time and height of the tide, but chiefly the former, especially in rivers and narrow seas. In the Rio de la Platà, for instance, after heavy gales from southeast to southwest, the water may rise 8 feet above the soundings shown on the chart; and continued winds from north northeast to north northwest may cause the water to fall 4 feet less than the soundings.

81. Tidal Streams.—Besides the knowledge of high and low water, and the comparative height of day and night tides, it will be necessary to observe the direction of the stream of flood and ebb, and the time at which the stream turns; but care should be taken not to confound the time of

the *turn of the tidal stream* with the time of high water. Mistakes have occurred by supposing that the turn of the tidal stream is the time of high water, but that is not so. The turn of the stream generally takes place at a different time from high water, except at the head of a bay or creek. The stream of flood runs for some time, often for hours, after high water. In the same way, the stream of ebb runs for some time after low water. Again, a stream, or current, due to tides may, in certain localities, flow in the offing for a long time, perhaps an hour or more after the tide has turned along the shore. It is of more practical importance to a navigator to be posted on the direction and strength of tidal streams than to know the exact time of high and low water. He is then enabled to so shape his course as to counteract the effect of the current. To this end, sailing directions and charts of the locality in which the ship is navigating should be carefully studied by the navigator.

82. Tide Tables and Charts.—Attention is called to the Navigator's Guide Charts of the English Channel With Its Tides and Currents, also of Vineyard Sound and Buzzard's Bay, published by the United States Hydrographic Office. Also to the Tide Tables (for the world) published by the United States Coast and Geodetic Survey. Tide tables showing the hourly state of the tide on the coasts of the United States are published by Capt. G. W. Eldridge and others. These, with the lighthouse, beacon, and buoy lists published by the United States Hydrographic Office, are of valuable assistance to the navigator.

The Tide Tables published by the United States Coast and Geodetic Survey contain much valuable information and give the times, heights, and direction of currents at certain principal ports of the world, which are regarded as standard ports, in reference to tidal data. From these tables, the time of high water can be obtained to a greater degree of accuracy than by any other method. They also contain what are known as current diagrams for certain important ports on the Atlantic seaboard.

Tables 46 and 47 (Bowditch) give the correct establishments of all the principal ports along the Atlantic and Pacific coasts and a great many ports of the world. These data may also be obtained directly from charts.

83. To Compute the Time of High Water.—To find, by calculation, the approximate time of high water at any given place, proceed as follows:

Rule.—*Find the moon's meridian passage at the given place, according to directions given in Nautical Astronomy, Part 2. To this time, add the tide hour or establishment found on charts or in Tables 46 and 47.**

The result would be the time of high water if the lunitidal interval did not vary.

EXAMPLE.—Find the time of high water at Charleston, South Carolina, November 19, 1899, civil time, the longitude of Charleston being 80° W.

SOLUTION.—

☽ Mer. passage, Nov. 18 =	$13^h\ 9.5^m$	Diff. in 1^h =	2.29^m
Corr. for Long. W =	$+\ 12.1^m$	Long. in time =	$\times\ 5.3^h$
L. M. T. of passage, Nov. 18 =	$13^h\ 21.6^m$	Corr. =	12.137^m

Or, Nov. 19 = $1^h\ 21.6^m$ A. M.
Establishment = $7^h\ 26^m$ (Mean interval column, Bowditch)

Approx. time of H. W. = $8^h\ 47.6^m$ A. M., Nov. 19, 1899. Ans.

84. If the changes of lunitidal interval from half-monthly inequality were the same for all ports, it would be easy, by a table of a single column, to apply the required correction to the time of high water when the moon was not at full and change. However, the general law of the change is the same, and, by knowing the greatest and least lunitidal interval for any port, it is possible to determine, by computation, the change of interval.

The ports having nearly the same difference of greatest and least interval are grouped together, and the correction to be applied to the establishment, according to the *age* of the moon, is given in Table IV. This table is arranged in three

* Bowditch's "American Navigator."

groups. Group (*a*) includes the ports of England and Western Europe in general; group (*b*), the ports on the eastern, or Atlantic, coast of the United States; group (*c*), the ports on the western coast of Florida, and on the western, or Pacific, coast of the United States. The table is arranged on the supposition that the correct establishment is used, which is the case for the more important ports of Tide Tables 46 and 47 (Bowditch).

TABLE IV

CORRECTION GROUPS

Time of Moon's Transit Hours	Correction Group (*a*) Minutes	Correction Group (*b*) Minutes	Correction Group (*c*) Minutes
0	add 41	add 19	0
1	add 17	add 6	subt. 17
2	subt. 11	subt. 8	subt. 32
3	subt. 27	subt. 16	subt. 44
4	subt. 40	subt. 22	subt. 47
5	subt. 47	subt. 24	subt. 35
6	subt. 41	subt. 19	subt. 0
7	subt. 17	subt. 6	add 17
8	add 11	add 8	add 32
9	add 27	add 16	add 44
10	add 40	add 22	add 47
11	add 47	add 24	add 35

TABLE V

AVERAGE OF CORRECTIONS

Time of Moon's Transit Hours	Correction Minutes
0	0
1	subt. 18
2	subt. 37
3	subt. 49
4	subt. 56
5	subt. 55
6	subt. 40
7	subt. 22
8	subt. 3
9	add 9
10	add 16
11	add 15

In other parts of the world than those mentioned in groups (*a*), (*b*), and (*c*), the half-monthly inequality is little known. Table V, formed by averaging the three columns of Table IV, will probably give a sufficient approximation. The corrections of Table V are to be applied to the *common*, or *vulgar*, *establishment*. The use of Table IV is illustrated in the following example.

EXAMPLE.—Find the time of high water at Portland, Maine (longitude 70° 12′ W), December 13, 1899, civil time.

SOLUTION.—Find first the local time of the moon's meridian passage and then apply factors taken from table as follows:

☽ Mer. passage, Dec. 12 =	$8^h\,16.6^m$	Diff. in 1^h =	2.16^m
Corr. for Long. W =	$+\quad 10.1^m$	Long. in time =	$\times\, 4.7^h$
L. M. T. of passage, Dec. 12 =	$8^h\,26.7^m$	Corr. =	10.152^m

Establishment =	$11^h\,25^m$ (Mean interval, Bowditch)
Corr., Table IV =	$+\quad 12^m$ (By proportion)
Corr. Interval =	$11^h\,37^m$
Add time of ☽ Mer. passage =	$+\ 8^h\,26.7^m$
	$20^h\ \ 3.7^m$
Subtract	$12^h\ \ 0^m$
Time of H.W., Portland, Dec. 13 =	$8^h\ \ 3.7^m$ A. M. Ans.

85. The diurnal inequality due to changes of the moon's declination causes a tide once in 24 hours. This inequality increases the height of the morning tide, and decreases the next, or afternoon, high tides, or vice versa. The diurnal inequality affects the time and the height of both high and low water.

In most of the ports of the Gulf of Mexico, this diurnal tide is the only marked one, except when the moon is near the equator. In the ports of Great Britain, Ireland, France, and Spain, the diurnal inequality in height is marked, but in time is inconsiderable; on the Atlantic Coast of the United States, it is *small* both in *time* and in *height*.

This inequality increases in passing along the Straits of Florida to the western coast of Florida, and the semidiurnal tides almost disappear from Cape San Blas to the mouth of the Mississippi River, reappearing to a slight degree on the coast of Texas, and again being merged in the diurnal tide from Aransas Pass to Vera Cruz, and probably southward.

The small tide of the day is frequently called, by navigators, a *half tide;* and in speaking of the large and small tides of the day, they are called *tide and half tide*. On the western coast of the United States, the diurnal inequality of the tide is large, both in time and in height, amounting at San Francisco, at its greatest value, to $2\frac{1}{2}$ hours of time and 4 feet of height. This inequality is probably larger on the west coast of South America, but reliable information in regard to the tides of these localities are lacking.

Table VI will give the corrections for the daily inequality in time and height for the Pacific Coast of the United States to within about 8 minutes of time and 3 inches of height. The quantities in this table are the corrections to be applied to the times of high or low water obtained by means of the rule of Art. **83** and corrected by Table IV.

86. Directions for Using Table VI.—Find from the Nautical Almanac the number of days elapsed since the moon's greatest declination, or, if before, the number of days to that time. With this, enter Table VI in the first column, and opposite find the correction in the second column.

TABLE VI

CORRECTIONS FOR INEQUALITIES ON THE PACIFIC COAST

Days From Moon's Greatest Declination	Lunitidal Interval		Height	
	High Water Minutes	Low Water Minutes	High Water Feet	Low Water Feet
0	64	38	1.0	1.8
1	62	37	0.9	1.8
2	55	35	0.9	1.6
3	45	31	0.8	1.4
4	33	23	0.7	1.0
5	22	18	0.4	0.7
6	9	6	0.2	0.3
7	0	0	0	0

When the moon's declination is north, the correction is to be subtracted; when south, it is to be added.

When the moon's declination is zero, the correction is nothing. The fourth and fifth columns give the corrections for the heights of mean high water and mean low water for the same days. The corrections for the heights of low water follow the same rule as those for the times of high water; but for the heights of high water they are the contrary, that

is, they are to be subtracted when the former are to be added, and vice versa.

The effects of this inequality are as follows: The moon's declination being north, the high water next following the moon's transit will be earlier and higher than the average, the next low water later and lower, the next high water later and lower, and the next low water earlier and higher; when the moon's declination is south, the first high water is later and lower, and the next low water earlier and higher, the next high water earlier and higher, and the next low water later and lower, by the amounts given in the table.

EXAMPLE.—Find the time of high water at San Francisco, California (longitude 122° 24′ W), October 22, 1899.

SOLUTION.—By the approximate method, neglecting corrections of Tables IV and VI,

☽ Mer. passage, Oct. 21	= $14^h\,28.5^m$	Diff. in 1^h =	2.31^m
Corr. for Long. W	= + 18.7^m	Long. in time =	8.1^h
L. M. T. of passage, Oct. 21	= $14^h\,47.2^m$	Corr. =	18.711^m
Establishment	= $12^h\,6^m$		

Approx. time of H. W., Oct. 21 = $26^h\,53^m$, or, Oct. 22, at $2^h\,53^m$ P. M. Ans.

SOLUTION.—By the rigorous method,

L. M. T. of ☽ Mer. passage, Oct. 21 =	$14^h\,47.2^m$
Or, Oct. 22 =	$2^h\,47^m$ A. M.
Corr. for $2^h\,45^m$ =	− 41^m [Table IV, group (*c*)]
Corr. L. M. T. of passage, Oct. 22 =	$2^h\,6^m$ A. M.
The Nautical Almanac shows the greatest north declination on the given day; therefore, by entering Table VI, opposite 0 is found Decl. 64^m (= $1^h\,4^m$), and since the moon's declination is north, the correction is subtractive, =	− $1^h\,4^m$
Oct. 22 =	$1^h\,2^m$ A. M.
Establishment =	+ $12^h\,6^m$
Corr. time of H.W. San Fran., Oct. 22 =	$13^h\,8^m$ A. M.

Or, Oct. 22 at $1^h\,8^m$ P. M. civil time. Ans.

It is evident that if the corrections had been neglected, the time of high water would have been $1^h\,45^m$ in error. The table also shows that this high water would be 1 foot higher

than the average high water, and the next low water 1.8 feet lower. The next high water in the morning of October 23 would be 1 foot lower than the average, or 2 feet lower than the above high water; the next low water 1.8 feet higher than the average, or 3.6 higher than the preceding one.

87. Usually, the meridian passage of the day preceding the civil date must be taken in order to find the time of high water on a given civil date; it may also be necessary to add 12 hours to the longitude, giving the time of the moon's lower meridian passage, in order to get the morning or afternoon high water that may be desired.

EXAMPLE.—Find the time of the afternoon high water at Delaware Breakwater (longitude 75° W), November 19, 1899.

SOLUTION.—The Greenwich mean time of the moon's meridian passage Nov. 18, 1899, is equal to $13^h\ 9.5^m$, and by adding the establishment, $8^h\ 0^m$, it will give Nov. 18, $21^h\ 9.5^m$ or, Nov. 19, A. M. The high water then occurs after a lower meridian passage, so that the time of the moon's meridian passage should be corrected for $75° + 180°$, or $5^h + 12^h$ of longitude. The required time of high water is then found as follows:

☽ Mer. passage, Nov. 18	=	$13^h\ 9^m$	Diff. in 1^h	=	2.29^m
Corr. for Long. W in time $+ 12^h$	=	$+\ \ 39^m$	Long.	=	$\times\ 17^h$
L. M. T. of passage, Nov. 18	=	$13^h\ 48^m$	Corr.	=	38.93^m
Add 12^h		$12^h\ 0^m$			
Nov. 18	=	$25^h\ 48^m$			
Establishment	=	$+\ 8^h\ 0^m$			
Approx. time H. W., Nov. 18	=	$33^h\ 48^m$			
Which is equal to Nov. 19	=	$9^h\ 48^m$ P. M.			
Corr. Table IV	=	$-\ \ 4^m$			
		$9^h\ 44^m$			
Corr. Table VI	=	$-\ 1^h\ 2^m$ (Declination north)			
Corr. time of H. W., Delaware Breakwater, Nov. 19	=	$8^h\ 42^m$ P. M. Ans.			

ELDRIDGE'S ILLUSTRATION OF PECULIAR TIDAL ACTIONS

88. The following characteristic letter and the accompanying chart, Fig. 15, reproduced from Capt. Geo. W. Eldridge's "Tide Book and Marine Directory," for 1900, will serve as an excellent illustration, showing as it does the great necessity of studying the tides and tidal currents, as given in sailing directions and in pilot and tidal charts, when navigating in localities where a neglect or a mistake in properly allowing for such currents may prove disastrous.

MY DEAR CAPTAIN AND MR. MATE:

As I cannot talk with you, I will do the next thing to it. I will write you a letter.

Do you know Captain and Mr. Mate, of a place on the Atlantic Coast that is called "The Graveyard?" I propose to tell you something about it, and do what I can to keep vessels out of it. "The Graveyard" so called, is that part of the coast which lies between Sow and Pigs Rocks and Naushon Island. This place has been called "The Graveyard" for many years, because many a good craft has laid her bones there, and many a captain has lost his reputation there also. If a vessel gets into this graveyard, there must be a cause for it. Did it ever occur to you that seldom does a vessel go ashore on Gay Head, or on the south side of the Sound? but that hundreds of them have been piled up in "The Graveyard," or on the north side of the Sound? I will explain why this is so: if you are bound into Vineyard Sound in thick weather, you will probably refer to the "Gay Head and Cross Rip" table in my book to see when the tide turns in or out. You will notice at the head of each table that it says: "This table shows the time that the current turns easterly and westerly off Gay Head in ship channel." That means off Gay Head when it bears about south. Now, as a rule, captains figure on the current, after they leave the lightship, as running easterly into the Sound, when, as a matter of fact, the first of the flood between the lightship and Gay Head runs nearly north; and the current does not begin to run to the eastward until you are well into the Sound, as shown by the chart on the next page, Fig. 15. Vessels bound into Vineyard Sound from the westward will have the current of *ebb* on the *starboard* bow and the current of *flood* nearly *abeam*.

I have explained this matter, and I leave the rest to your judgment and careful consideration; and thus you will undoubtedly keep your vessel out of "The Graveyard." Yours for a fair tide,

GEO. W. ELDRIDGE

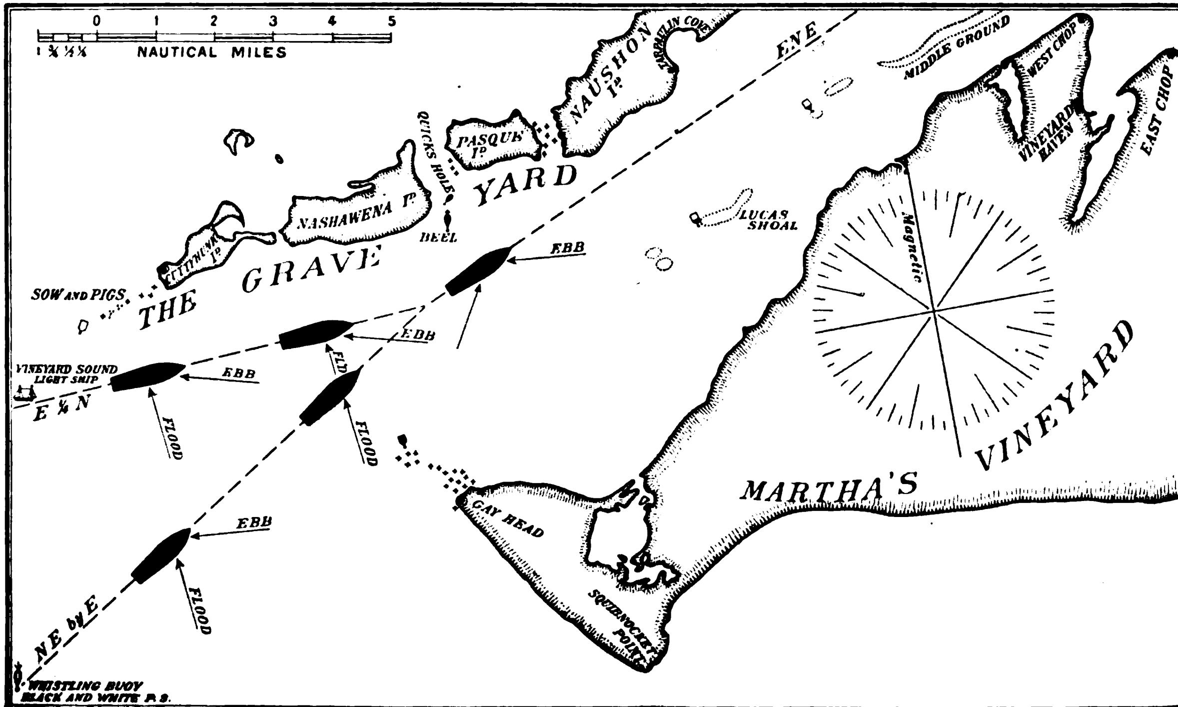
0 1 2 3 4 5
1 ¾ ½ ¼
NAUTICAL MILES
NAUSHON Iᵈ
TARPAULIN COVE
PASQUE Iᵈ
QUICKS HOLE
NASHAWENA Iᵈ
BEEL
THE GRAVE YARD
SOW AND PIGS
VINEYARD SOUND LIGHT SHIP
E ¼ N
E N E
MIDDLE GROUND
WEST CHOP
VINEYARD HAVEN
EAST CHOP
LUCAS SHOAL
Magnetic
EBB
FLD
FLOOD
NE by E
WHISTLING BUOY
BLACK AND WHITE P. S.
GAY HEAD
SQUIBNOCKET POINT
MARTHA'S VINEYARD

Fig. 15

Fig. 15 represents the chart of the western entrance to Vineyard Sound referred to in Captain Eldridge's letter. The directions of the arrows show the remarkable conditions of the tides in that locality, an incoming ship being affected by the tidal currents of both ebb and flood on the same side, the former setting on the starboard bow, the latter nearly abeam. It is evident that, if not properly allowed for, the effects of these currents will naturally tend to set the vessel toward the northern side of the Sound and, eventually, land her in "The Graveyard," so called on account of the many strandings that have occurred there.

NOTES RELATING TO THE HANDLING OF STEAMERS IN HEAVY WEATHER

89. To Lie-To a Steamer in a Gale.—While the term "lie-to" has been frequently used in connection with the subject of revolving storms, and while it properly belongs to the subject of seamanship, which is not treated here, a brief explanation of the operations conveyed by that term may not be altogether out of place.

The best way in which to heave-to, or lie-to, a steamer in a gale will depend to a great extent on the peculiarity of the steamer herself. By "peculiarity of a steamer" is meant the tendency in motions, and otherwise, that distinguishes her from other ships of the same class and under similar conditions. Some steamers seem to lie-to more easily and more comfortably with their bows toward the direction of the sea, that is, against the waves, than in any other way, while others will lie-to best with the sea 3 or 4 points on the bow. In both cases, the engine is used sufficiently to give the steamer proper steerageway. In violent gales, and in cases where machinery is disabled, it is sometimes necessary to use a *drag*, or *sea anchor*, in order to have the ship lie-to. This applies to small and medium-sized ships. As for steamships of large tonnage, with considerable length and depth, the theory advanced by some seamen is that such vessels will lie-to best in the trough of the sea, or in a direction

parallel to the crest of the waves. This opinion, however, is not entertained by all seamen. To cause a vessel to lie-to in the trough of a heavy sea is, in the opinion of the writer, a risky undertaking, especially for lightly loaded vessels or for vessels in ballast, as they are liable to turn turtle without warning. This may not occur from the first or second sea striking the vessel; one sea, however, may list the ship to such an extent as to cause the cargo, or ballast, to shift, and the next one will complete the catastrophe. The theory generally accepted is that the easiest position for a ship in heavy weather, when unable to pursue her course, is the one that she would take if left at rest and relieved from the constraint of engines, rudder, and sails. As a rule, she will then fall off until she has the sea abaft the beam, the propeller acting as a drag on the stern. If, under such circumstances, she is rolling dangerously, she may be kept more steady by using head-sails, or by keeping the engines going sufficiently to give her steerageway, in combination with a judicious use of oil, since experience has proved that *a steamer may safely run with the sea aft or on the quarter, provided she runs very slowly.*

90. Lieut. Commander, now Captain, A. M. Knight, United States Navy, in his admirable treatise on seamanship,* after a lengthy discussion of the various phases of the behavior and methods of handling a steamer in heavy weather, sums up the result of his investigations as follows:

"A ship will, as a rule, be safest and most comfortable when end-on, or nearly end-on, to the sea, and *drifting before it.*

"If, by the use of sails, a drag, or any other means, she can be held bows-on, while still being allowed to drift, this is probably the best way to lay her to; but if she cannot be held up without being forced into the sea, it will be because of the natural drag of the stern and propeller, and in this case advantage should be taken of this drag to hold her more or less directly *stern-on*, allowing her to drift in this way.

* "Modern Seamanship," D. Van Nostrand Co., New York, 1900.

"Even if the position she takes in drifting is nearly in the trough of the sea, it will usually be found that she is easier in this position than in any other, the use of oil in this case being of particular importance.

"If the position that she takes in drifting proves to be one in which she rolls dangerously, she may be run just fast enough to steer, *but no faster*, and so keep the course that is found more comfortable."

91. Use of Oil in Stormy Weather.—Navigators cannot be reminded too often of the use of oil in stormy weather. The importance of using oil is well illustrated by the fact that it is now recognized in standard books on seamanship. The International Marine Conference at Washington recommended that "the several governments require all their seagoing vessels to carry a sufficient quantity of animal or vegetable oil, for the purpose of calming the sea in rough weather, together with suitable means for applying it."

Thick and heavy oils are the best. Mineral oils are not so effective as animal or vegetable oils. Raw petroleum has given favorable results, but is not so good when refined. Certain oils, like coconut oil and some kinds of fish oil, congeal in cold weather, and are therefore useless, but may be mixed with mineral oils to advantage. As a general rule, probably the best way to use oil is to fill the forward closet bowls with oakum and oil, and let the oil drip out slowly through the waste pipes. Another simple and easy way to distribute oil is by means of canvas bags about a foot long; these are filled with oakum and oil, pierced with holes by means of a coarse sail needle, and held by a lanyard.

When running before a gale, use oil from bags at the catheads, or from forward waste pipes; if yawing badly and threatening to broach-to, use oil forwards and abaft the beam, on both sides. If lying-to, distribute oil from the weather bow. With a high-beam sea, use oil bags at regular intervals along the weather side. In a heavy cross-sea, have bags along both sides. When steaming into a heavy head-sea, use oil through the forward closet pipes. There are

many other cases where oil may be used to advantage, such as lowering and hoisting boats, riding to a sea anchor, crossing rollers or surf on a bar, and from life boats and stranded vessels.

92. Drag, or Sea Anchor.—The **drag,** or **sea anchor,** a type of which is shown in Fig. 16, is a contrivance used at sea to prevent the ship from drifting too fast during a violent gale under bare poles, and to keep the bow or the stern of a vessel toward the sea. The drag is constructed on the same

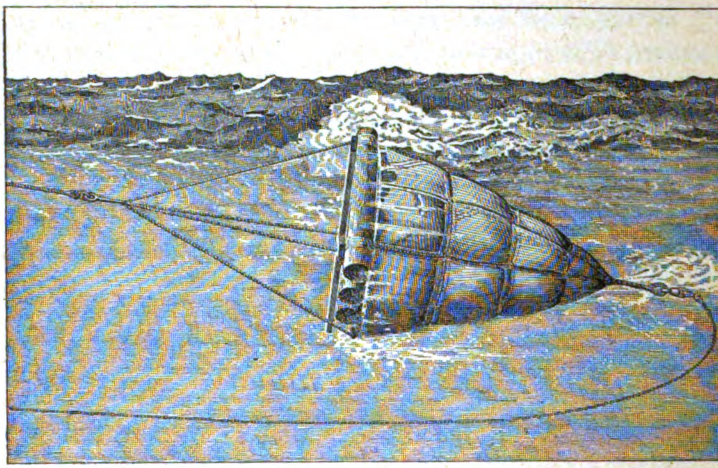

FIG. 16

principles as the ordinary log chip, or rather on the principle of the parachute used by aeronauts. The ship being exposed to the full force of the wind will drift faster than the drag, which is practically submerged; hence, the latter will act as a check to the backward progress of the former.

Several patent drags are now in use, the **cornucopia drag** being the one commonly found on board American ships. This drag consists of an iron ring—varying in diameter according to the *tonnage* of the vessel—to which is laced a cone-shaped canvas bag, at the apex of which a small iron ring is attached. The whole is weighted in such a manner as to keep the mouth of the drag below the surface of

the water, in order to insure the greatest resistance. The towing line to which the drag is attached is usually led in through the hawse pipe and is secured to bits, in cases where the bow is held against the sea. When taking in the drag, the tripping line attached to the small ring is manned; by this line the bag is turned over and the contrivance easily pulled on board.

A sea anchor of the conical type, whose length is about equal to its diameter, usually has a tendency to broach and revolve about its axis, thus often fouling the tripping line and rendering it difficult to pull in the anchor. To overcome this, the towing line as well as the tripping line should be provided with swivels; or, the mouth of the drag should be fitted with cork and weights in such a manner as to keep the whole steady below the surface of the sea. Experiments have shown that the best results in sea anchors, so far as steadiness and uniform resistance are concerned, are obtained by a conical canvas bag whose length is about three times its diameter.

In cases where a vessel is not provided with a regular sea anchor, a substitute may be readily constructed from such materials as may be available. For instance, spars may be lashed together, bridled, and weighted with a kedge anchor or chains, so that the whole will float in a vertical position, the upper spars being even with the surface of the water. This substitute is then thrown overboard, secured, and used exactly the same as the patent drag.

93. As a rule, drags, or sea anchors, are seldom, if ever, used by large steamships, the reason for this probably being that when encountering winds of such violence as to make the use of a drag desirable, the work of getting out and putting in shape so heavy a drag as would be required by the size of the steamer is out of the question. Besides, the drag, once out, will materially hamper the prompt execution of any maneuver that must be made. For small-sized steamers and sailing vessels, the drag is undoubtedly very useful in riding out a gale with safety and comfort, although

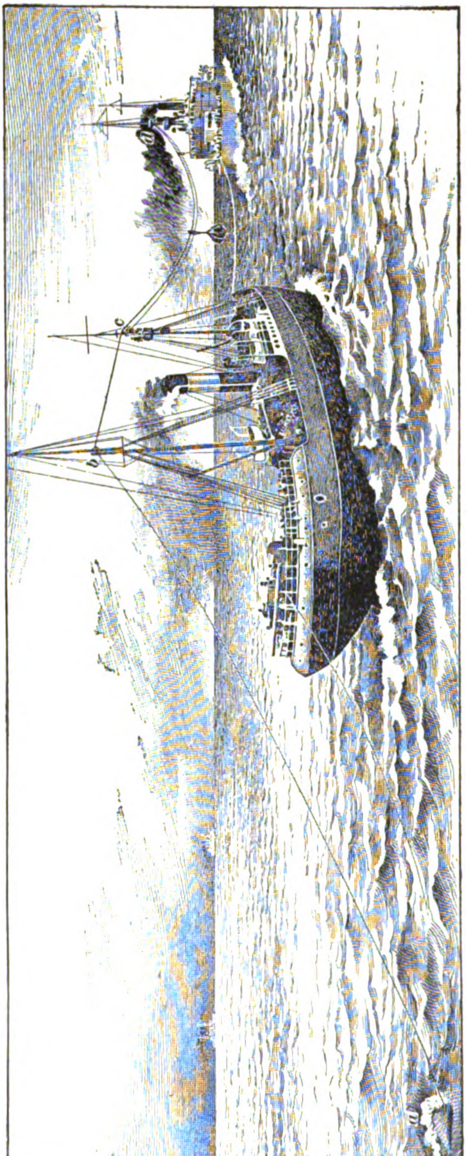

FIG. 17

many shipmasters, with a life-long experience at sea, profess never to have used it.

94. Use of Sea Anchors in Coaling Ships at Sea. Recently, the sea anchor has come into a new practical use in the coaling of ships at sea and under way, as shown in Fig. 17. The anchor is used here to keep the cable on which the coal bags are transferred at a uniform tension, no matter how the collier may plunge, roll, or otherwise alter its distance from the towing ship. This is accomplished by having a conical sea anchor, or drag, *a* attached to the end of the cableway *d c b* between the two ships. At *d* one end of the cable is secured, and at *c* and *b*, it runs through blocks attached to the mastheads of the collier. These points *d*, *c*, and *b* are of about equal height. By steaming ahead at a suitable speed, the resistance of the sea anchor will keep the cable at the required tension. This permits the transfer of coal to the towing vessel while she is proceeding on her course, the collier being towed in the usual way by a hawser from her bow.

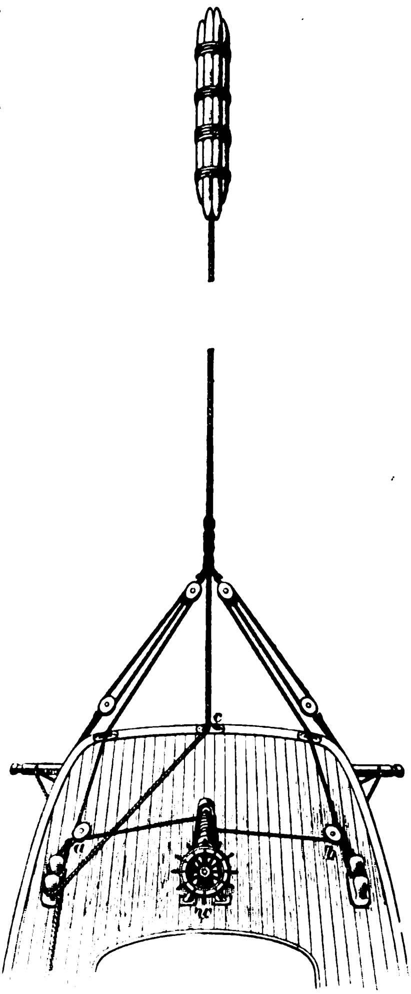

FIG. 18

95. Jury, or Temporary, Rudder.—In case a rudder becomes disabled so that it cannot be used, it should be either unshipped or secured in such a manner as to prevent it from doing damage to the hull. As to the rigging of a temporary rudder, no particular rules can be framed; circumstances and materials at hand will suggest the method to be adopted. The simplest, and perhaps the handiest, method of rigging a jury rudder for a small vessel is as follows: Lash several spars together (see Fig. 18) so as to form a float. To the under side, or lower edge, of this attach chains so that the whole will float nearly submerged when put in water. When ready, secure to the float a good, suitable line, or hawser, and launch it overboard; pay out as much line as is deemed necessary and fasten the line to the center part *c* of the stern. From each quarter have a tackle attached to the line at a suitable distance from *c*, as shown in the figure. Lead the running part of these tackles through the snatch blocks *a* and *b*, respectively, and thence to the barrel of the wheel *w*, to which they are applied in the same way as a common tiller rope. The ship can now be steered in exactly the same manner as with a rudder.

As a substitute for spars lashed together, as shown in Fig. 18, a drag may be used in nearly the same manner. This is done by towing the drag from the center of the taffrail, the apex of the drag being attached to the towing line. In this case, the iron ring, or hoop, is not used; instead, the mouth of the drag is bridled and connected by lines to each quarter. By pulling one of the lines attached to the bridle, the drag will inflate and produce resistance.

Before a temporary rudder is ready for service, the course of the vessel should be controlled by a judicious use of sails, or by sails and propeller in combination.

INTERNATIONAL RULES AND SIGNALS

SYSTEMS OF SIGNALING

INTERNATIONAL CODE SIGNALS

1. The object of the International Code of Signals is to supply a means of communication between ships meeting at sea and between ships and established signal stations on shore. This code has been adopted by all the leading maritime powers of the world, and the interpretations of the several thousand distinct signals composing the system have been translated into the language of each of these nations. Ships of different nationalities when meeting at sea are consequently enabled to communicate with each other, even though one is an American and the other a Greek, and neither commander is able to use the language of the other in conversation.

2. Old Code of Signals.—The old International Code of Signals, which was abolished January 1, 1902, had been in existence since 1857. It consisted of eighteen flags, representing the consonants of the alphabet, namely, one burgee, four pennants, thirteen square flags, besides a pennant called the *code signal*, which served also as the *answering pennant.* By this code, about 78,000 separate signals could be made. Each signal was made in one hoist, in one place, and without the use of distinguishing or repeating flags or pennants; and no hoist was composed of more than four flags.

3. New Code of Signals.—The new International Code of Signals, shown in Fig. 1, consists of twenty-six flags, namely, two burgees, five pennants, and nineteen square flags, besides the *code flag*, which is used also as the *answering pennant*. Of the twenty-six flags, ten are new, namely, *A*, *E*, *F*, *I*, *L*, *O*, *U*, *X*, *Y*, and *Z*; of these, *F* and *L* have been retained from the old code, but changed slightly, the former from a red pennant with a white circular spot to a red pennant with white cross-lines, the latter from alternating blue and yellow squares to yellow and black squares.

The new code, which was prepared under the supervision of the British Board of Trade and adopted by all maritime powers, with the exception of Turkey, went into effect January 1, 1902. All vessels that used the new code before that date were required to hoist as their code signal, or answering signal, the code flag with the fly tied to the halyards, *having above it a black ball*, or shape resembling a ball, as shown in the upper part of Fig. 1.

4. The Code Book.—The new code book published by the Bureau of Equipment, United States Navy Department, is divided into three parts.

Part I contains instructions showing how to make and how to answer a signal, accompanied by suitable examples. Then comes an alphabetical spelling table, numeral signals, urgent and important signals, compass signals, signals relating to money and all kinds of measurements, signals relating to latitude, longitude, time, barometer, thermometer, phrase signals formed with auxiliary verbs, and geographical signals. Of these signals, only those coming under the heading "urgent and important" are made with two flags in a hoist; all others are made with three flags in a hoist, with the exception of geographical signals, which are made with four flags in a hoist.

Part II contains an index of general vocabulary signals and a second list of geographical signals, in which the names of places are alphabetically arranged. The vocabulary signals are, with few exceptions, three-flag signals.

CODE FLAGS AND PENNANTS
INTERNATIONAL CODE OF SIGNALS

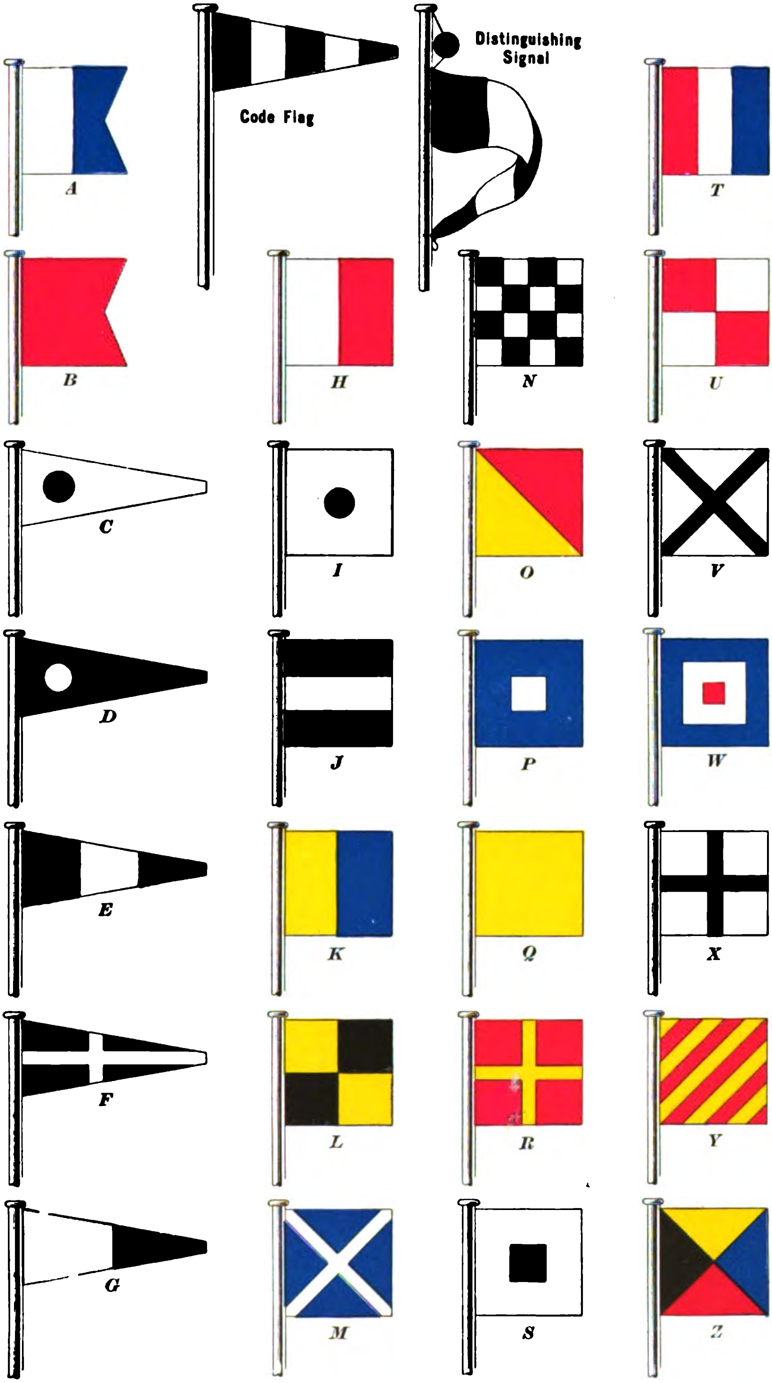

FIG. 1

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Part III contains a list of storm-warning display, life-saving, and time-signal stations of the United States, a list of Lloyd's signal stations throughout the world, and American, English, and French semaphore, distance, and wigwag codes.

5. In connection with the make-up and interpretation of signals, it is of importance that the beginner should learn first of all to distinguish the flags so as to be able to tell at a glance what letters are contained in a hoist; secondly, he should understand the distinctive character of the various signals as indicated by the form of the hoist or by the number of flags of which it is composed. All applicants for masters and officers' certificates are required to pass examinations on this subject. The best way to familiarize oneself with the system of signals and signaling is *practice* in combination with a careful study of the instructions given in the code book.

CHARACTER OF SIGNALS AS INDICATED BY THE NUMBER OF FLAGS IN A HOIST

6. One-Flag Signals.—The meaning of flags and pennants hoisted *singly* and with the code flag is found on pages 7 and 35 of the code book.

7. Two-Flag Signals.—Signals composed of two flags are urgent or important signals. They run from *A B* to *X Y.*

8. Three-Flag Signals.—Signals composed of three flags are either compass, measurement, auxiliary phrases, or general vocabulary signals. Compass signals run from *A B C* to *A S T*, signals relating to money from *A S U* to *A V J*, and those relating to weights and measures from *A V K* to *B C N.* Three-flag signals in which the code flag is uppermost relate to latitude, longitude, time, barometer, or thermometer.

9. Four-Flag Signals.—Signals composed of four flags are either geographical or alphabetical signals. All geographical signals begin with the letter *A* or *B* and run from *A B C D* to *B F A U.* All alphabetical signals commence with the letter *C.* Four-flag signals with the pennant *G* uppermost

are names of men-of-war. Four-flag signals with a square flag uppermost are names of merchant vessels, and are not in the code book.

10. Since each of the twenty-six letters of the alphabet is represented by a flag, it is evident that any word can be spelled by this system, and if the word to be spelled consists of more than four letters, two or more hoists must be used, as *no hoist is to contain more than four flags.* Explanations and instructions on this subject are to be found on pages 13 and 14 of the code book.

11. Illustrations of Hoists.—The principal forms of signals are shown in Fig. 2, where (*1*), (*2*), and (*3*) are urgent or important signals, (*4*) a compass signal, (*5*) a general vocabulary signal, and (*6*), (*7*), and (*8*) geographical signals. The interpretation of the respective signals is as follows:

(*1*)	*B* *O*	= Have lost all my boats.	Urgent or important signals.
(*2*)	*F* *P*	= Bad weather is expected.	
(*3*)	*M* *R*	= Have broken main shaft.	
(*4*)	*A* *Q* *J*	= Northeast by north.	Compass signal.
(*5*)	*O* *W* *L*	= I cannot make out the flags; hoist the signal in a better position.	General vocabulary signal.
(*6*)	*A* *E* *O* *J*	= Falmouth (England).	Geographical signals.
(*7*)	*A* *Z* *K* *G*	= Philadelphia, Pa.	
(*8*)	*A* *U* *G* *F*	= San Francisco, Cal.	

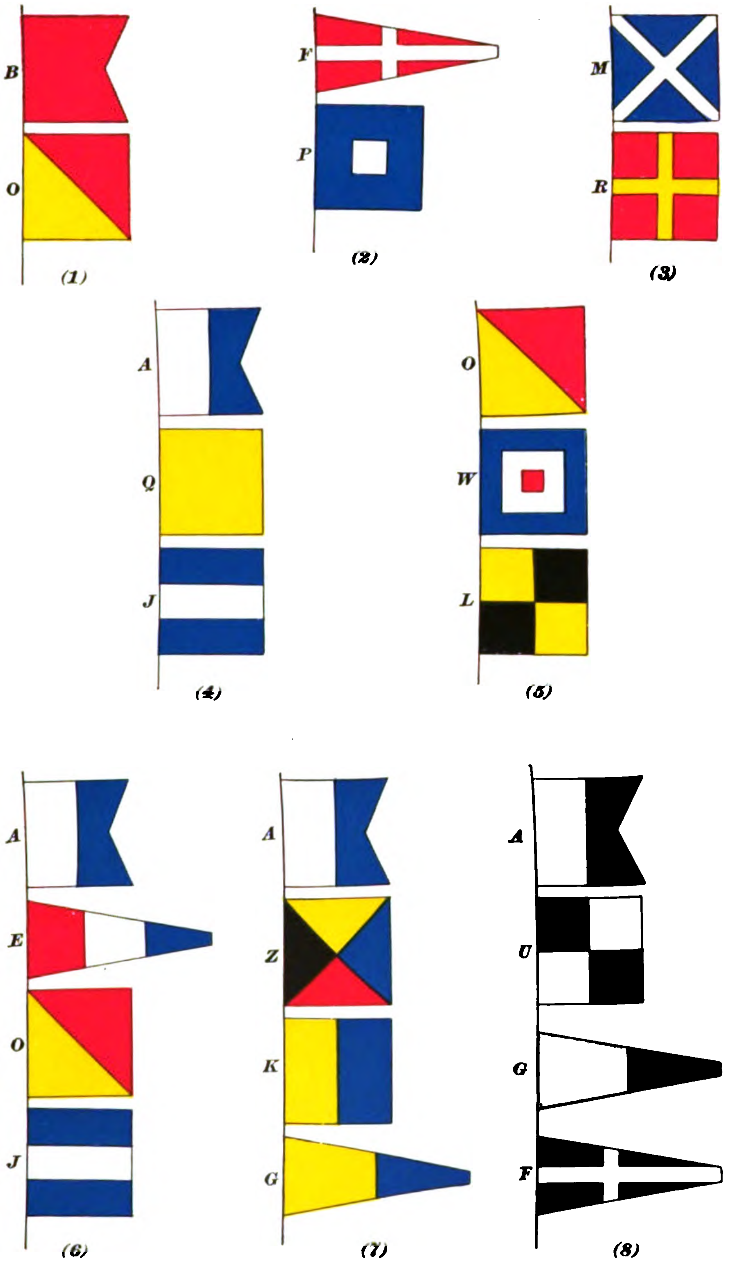

FIG. 2

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12. Position and Duration of Signals.—Signals should be hoisted where they can best be seen, and not necessarily at the masthead; also, each hoist should be kept flying until the other vessel has signified that the signal is understood. Care should be taken not to hoist a signal in an up-and-down position or with the uppermost flag down, which sometimes occurs when signals are sent up in a hurry.

13. Selected Signals.—The following is a selection of signals for the use of vessels meeting at sea, or for vessels in sight of signal stations. By committing these signals to memory, much delay in searching for them in the code book is obviated.

SIGNALS	MEANING
E C	What ship is that?
S I	Where are you from?
S H	Where are you bound?
S G	When did you sail?
U B	Do you wish to be reported?
U D	Report me, by telegraph, to Lloyd's.
U R Z	Report me all well.
U E	Report me, by telegraph, to owners.
U F	Report me, by telegraph, to Shipping Gazette.
U G	Report me to Lloyd's (either by post or telegraph).
U I	Report me to New York Herald office, London.
U J	Report me to New York Herald office, New York.
V J	I wish to signal; will you come within easy signal distance?
V M	Cannot distinguish your flag; come nearer.
V I	Repeat your signal.
S W	I wish to obtain orders from my owner—(name).
T D	There are no orders for you here.
T E	Wait for orders.
Q U	Will you forward my letters?
Q R	Send your letters
Y E	Want assistance.
Y L	Want immediate medical assistance.
N C	In distress; want immediate assistance.
D C	We are coming to your assistance.
C X	No assistance can be rendered; do the best you can for yourselves.
F H	Send a boat.
E U	Boat is going to you.
E X	Cannot send boat.

Signals	Meaning
B O	Have lost all my boats.
Code flag over *H*	Come nearer. Stop, or heave to. I have something important to communicate.
I F	Cannot stop to have any communications.
R Z	Where am I? What is my present position?
Q I B	What is your latitude brought up to the present moment?
Q Z K	What is your longitude brought up to the present moment?
Q H W	My latitude is . . .
Q Z F	My longitude by chronometer is . . .
X N	Will you show me your Greenwich time?
G U	Will you give me a comparison? Wish to get a rate for my chronometer.
I Q H	I have no chronometer.
G Q	My chronometer has run down.
M R	Have broken main shaft.
M W	One screw disabled; can work the other.
M Q	Engines completely disabled.
M X	Passed disabled steamer at . . .
H M	Vessel seriously damaged; wish to transfer passengers.
G Y	Can you spare me coal?
H C	Indicate nearest place I can get coal.
B I	Damaged rudder, cannot steer.
J D	You are standing into danger.
S A	Are there any men-of-war about?
X O	Beware of torpedo boats.
X P	Beware of torpedoes; channel (or fairway) is mined.
Y P	Want a tug (if more than one, number to follow).
Y O	Want provisions immediately.
Y R	Want water immediately.
C, or code flag over *C*	Yes, or affirmative.
D, or code flag over *D*	No, or negative.

DISTANT SIGNALS

14. Cone, Ball, and Drum Signals.—Distance signals are used when, in consequence of distance or the state of the atmosphere, it is impossible to distinguish the colors of the flags of the International Code and, therefore, to read a signal made by those flags; they also provide an alternative system of making the signals in the code, which can be adopted when the system of flags cannot be employed. Three methods of making distant signals are used: (1) by

cones, balls, and drums; (2) by balls, square flags, pennants, and whefts; and (3) by the fixed coast semaphore.

In calms or when the wind is blowing toward or from the observer, it is often difficult to distinguish with certainty between a square flag, pennant, and wheft, and as flags when hanging up and down may hide one of the balls and so prevent the signal from being understood, the system of cones and drums is preferable to that of flags, pennants, and whefts.

The following special distant signals are made by a single hoist followed by the "stop" signal. They are arranged numerically for reading off the signal.

2—"Preparative," "answering" or "stop" after each complete signal.

1, 2—Aground; want immediate assistance.

2, 1—Fire or leak; want immediate assistance.

2, 2—Annul the whole signal.

2, 3—You are running into danger; or, your course is dangerous.

2, 4—Want water immediately.

3, 2—Short of provisions; starving.

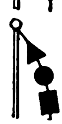
4, 2—Annul the last hoist; I will repeat it.

1, 1, 2—I am on fire.

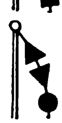
1, 2, 1—I am aground.

1, 2, 2—Yes, or affirmative.

1, 2, 3—No, or negative.



1, 2, 4—Send lifeboat.



1, 3, 2—Do not abandon the vessel.

1, 4, 2—Do not abandon the vessel until the tide has ebbed.

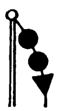
2, 1, 1—Assistance is coming.

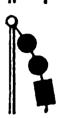

2, 1, 2—Landing is impossible.


2, 1, 3—Bar; or entrance is dangerous.


2, 1, 4—Ship disabled; will you assist me into port?


2, 2, 1—Want a pilot.


2, 2, 3—Want a tug; can I obtain one?


2, 2, 4—Asks the name of ship (for signal station) in sight; or, show your distinguishing signal.

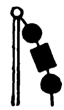

2, 3, 1—Show your ensign.


2, 3, 2—Have you any despatches (messages; orders; or telegrams) for me?

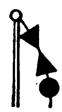

2, 3, 3—Stop, bring to, or come nearer; I have something important to communicate.

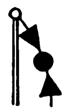

2, 3, 4—Repeat signal or hoist it in a more conspicuous position.

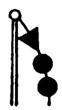

2, 4, 1—Cannot distinguish your flags; come nearer or make distant signals.


2, 4, 2—Weigh, cut, or slip; wait for nothing; get an offing.


2, 4, 3—Cyclone, hurricane, or typhoon expected.


3, 1, 2—Is war declared; or, has war commenced?


3, 2, 1—War is declared; or, war has commenced.


3, 2, 2—Beware of torpedoes; channel is mined.


3, 2, 3—Beware of torpedo boats.


3, 2, 4—Enemy is in sight.


3, 3, 2—Enemy is closing with you; or, you are closing with the enemy.


3, 4, 2—Keep a good lookout, as it is reported that enemy's men-of-war are going about disguised as merchant ships.


4, 1, 2—Proceed on your voyage.

15. The distant signal shown in Fig. 3, made with flag and ball, and pennant and ball, have their special signification beneath them.

You are running into danger — Fire or leak; want immediate assistance — Short of provisions; starving — Aground; want immediate assistance

FIG. 3

16. Weather-Bureau Stations.—The following Weather Bureau Stations on the coast of the United States are equipped with telegraph lines:

Atlantic Coast.—Nantucket, Massachusetts; Narragansett Pier and Block Island, Rhode Island; Norfolk and Cape Henry, Virginia; Currituck Inlet, Kitty Hawk, and Hatteras, North Carolina; Sand Key, Florida.

Pacific Coast.—Tatoosh Island, Neah Bay, East Clallam, Twin Rivers, Port Crescent, and North Head, Washington; Point Reyes Light, San Francisco, and Southeast Farallone, California.

Lake Huron.—Thunder Bay Island, Middle Island, and Alpena, Michigan.

Of these stations, the following are equipped with International Code Signals, and communication can be had with them for the purpose of obtaining information concerning the approach of storms and weather conditions in general, and for the purpose of sending telegrams to points on commercial lines.

Nantucket, Massachusetts; Block Island, Rhode Island; Cape Henry, Virginia; Hatteras and Kitty Hawk, North Carolina; Sand Key and Jupiter, Florida; Tatoosh Island, and Neah Bay, Washington; Point Reyes Light and Southeast Farallone, California.

Any message signaled by the International Code, as adopted or used by England, France, America, Denmark, Holland, Sweden, Norway, Russia, Greece, Italy, Germany, Austria, Spain, Portugal, and Brazil, and received at these

telegraph signal stations, will be transmitted and delivered to the address on payment at the receiving station of the charges for the telegram. All messages received from or addressed to the War, Navy, Treasury, State, Interior, or other official departments at Washington are telegraphed without charge over the Weather Bureau lines.

17. Distress Signals.—When a vessel is in distress and requires assistance from other vessels or from the shore, the following are the signals to be used by her, either together or separately:

Daytime.—1. A gun or other explosive signal fired at intervals of about a minute.

2. The International Code signal of distress indicated by *N C*.

3. The distant signal, consisting of a square flag, having either above or below it a ball or anything resembling a ball.

4. The distant signal, consisting of a cone pointing upwards, having either above or below it a ball or anything resembling a ball.

5. A continuous sounding with any fog-signal apparatus.

At Night.—1. A gun or other explosive signal fired at intervals of about a minute.

2. Flames on the vessel (as from a burning tar barrel, oil barrel, etc.).

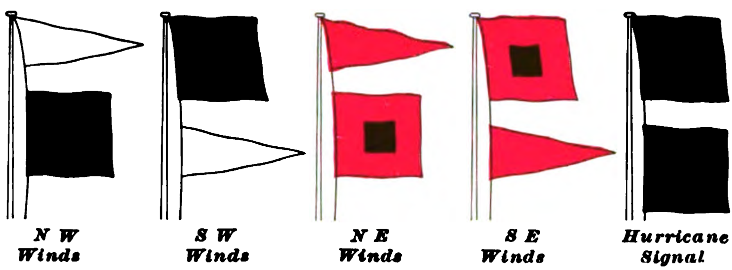
3. Rockets or shells, throwing stars of any color or description, fired one at a time at short intervals.

4. A continuous sounding with any fog-signal apparatus.

Not Under Control.—A vessel temporarily disabled at sea through the breaking down of her engines, or from other causes, but not requiring assistance, should in daytime hoist two black balls, or shapes resembling balls, one above the other; if at night, two red lights should be hoisted in a similar position. Such signal means, "I am not under control," and it should be kept hoisted until repairs are effected or until the vessel is in a position to proceed on her voyage. (See also Art. 4, Rules of the Road.)

UNITED STATES WEATHER BUREAU SIGNALS

Wind and Storm Signals



Flags should be 8 feet square; pennants, 5 feet hoist, 12 feet fly.

Temperature and Weather Signals

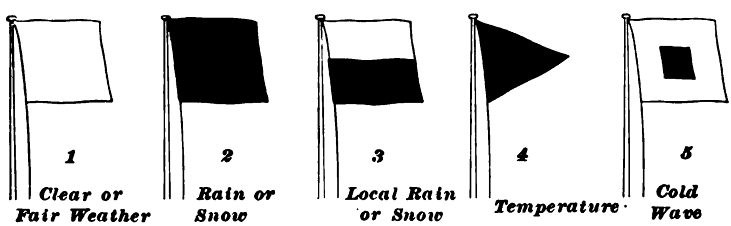


Fig. 4

When No. *4* is placed above Nos. *1*, *2*, or *3*, it indicates warmer; when below, colder; when not displayed, the temperature is expected to remain about stationary. No. *5* is used also to indicate anticipated frosts.

18. Storm Signals.—A red flag with a black center displayed at any station along the coast of the United States or dependencies indicates that a storm of marked violence is expected. The pennants displayed with the flags indicate the direction of the wind: red, easterly (from northeast to south); white, westerly (from southwest to north). The pennant above the flag indicates that the wind is expected to blow from the northerly quadrants; below, from southerly quadrants, as shown in the upper part of Fig. 4. At night, a red light indicates easterly winds, and a white light above a red light, westerly winds.

19. Hurricane Warning.—Two red flags with black centers, displayed one above the other, indicate the expected approach of tropical hurricanes, and also of those extremely severe and dangerous storms that occasionally move across the lakes and northern Atlantic Coast. Hurricane warnings are not displayed at night.

Storm signals are displayed by the United States Weather Bureau at 141 stations situated along the Atlantic and Gulf Coasts, and at 27 stations situated on the Pacific Coast of the United States.

20. Signals for Pilot.—The following signals, when used or displayed together or separately, shall be deemed to be signals for a pilot:

Daytime. 1. The Jack, or other national ensign, usually worn by merchant ships, having around it a white border one-fifth the breadth of the flag, to be hoisted at the foretop.

2. The International Code pilot signal indicated by *P T*.

3. The International Code flag *S*, with or without the code pennant over it.

4. The distant signal consisting of a cone point upwards, having above it two balls, or shapes resembling balls.

At night.—1. The pyrotechnic light, commonly known as a "blue light," every 15 minutes.

2. A bright white light, flashed or shown at short or frequent intervals, just above the bulwarks, for about a minute at a time.

INTERNATIONAL RULES TO PREVENT COLLISIONS AT SEA

RULES OF THE ROAD

21. The following regulations for navigation on the high seas, commonly known as the "Rules of the Road," the outcome of the International Marine Conference held in Washington, District of Columbia, during the winter of 1889–90, were approved by Congress and signed by the President on August 19, 1890. The act took effect on July 1, 1897.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the following regulations for preventing collisions at sea shall be followed by all public and private vessels of the United States upon the high seas and in all waters connected therewith, navigable by seagoing vessels.

Preliminary

In the following rules every steam vessel which is under sail and not under steam is to be considered a sailing vessel, and every vessel under steam, whether under sail or not, is to be considered a steam vessel.

The words "steam vessel" shall include any vessel propelled by machinery.

A vessel is "under way" within the meaning of these rules when she is not at anchor, or made fast to the shore, or ground.

The word "visible" in these rules when applied to lights shall mean visible on a dark night with a clear atmosphere.

Lights to be Exhibited From Sunset to Sunrise

Art. 1. The rules concerning lights shall be complied with in all weathers from sunset to sunrise, and during such time no other lights which may be mistaken for the prescribed lights shall be exhibited.

Masthead Light on Steamer

Art. 2. A Steam Vessel When Under Way Shall Carry—(*a*) On or in front of the foremast, or if a vessel without a foremast, then in the fore part of the vessel, at a height above the hull of not less than 20 feet, and if the breadth of the vessel exceeds 20 feet, then at a height

above the hull not less than such breadth, so, however, that the light need not be carried at a greater height above the hull than 40 feet, a bright white light, so constructed as to show an unbroken light over an arc of the horizon of twenty points of the compass, so fixed as to throw the light ten points on each side of the vessel, namely, from right ahead of the points abaft the beam on either side, and of such a character as to be visible at a distance of at least 5 miles.

Side Lights on Steamer

(*b*) On the starboard side a green light so constructed as to show an unbroken light over an arc of the horizon of ten points of the compass, so fixed as to throw the light from right ahead to two points abaft the beam on the starboard side, and of such a character as to be visible at a distance of at least 2 miles.

(*c*) On the port side a red light so constructed as to show an unbroken light over an arc of the horizon of ten points of the compass, so fixed as to throw the light from right ahead to two points abaft the beam on the port side, and of such a character as to be visible at a distance of at least 2 miles.

(*d*) The said green and red side lights shall be fitted with inboard screens projecting at least 3 feet forwards from the light, so as to prevent these lights from being seen across the bow. (See Fig. 5.)

Additional White Light May Be Carried by Steamer Under Way

(*e*) A steam vessel when under way may carry an additional white light similar in construction to the light mentioned in subdivision (*a*). These two lights shall be so placed in line with the keel that one shall be at least 15 feet higher than the other, and in such a position with reference to each other that the lower light shall be forwards of the upper one. The vertical distance between these lights shall be less than the horizontal distance.

Towing Lights for Steamer

ART. 3. A steam vessel, when towing another vessel, shall, in addition to her side lights, carry two bright white lights in a vertical line one over the other (see Fig. 5), not less than 6 feet apart, and when towing more than one vessel shall carry an additional bright white light 6 feet above or below such lights, if the length of the tow, measuring from the stern of the towing vessel to the stern of the last vessel towed, exceeds 600 feet. Each of these lights shall be of the same construction and character, and shall be carried in the same position as the white light mentioned in Art. 2 (*a*), excepting the additional light, which may be carried at a height of not less than 14 feet above the hull.

Such steam vessel may carry a small white light abaft the funnel or aftermast for the vessel towed to steer by, but such light shall not be visible forward of the beam.

Lights for Vessels Not Under Command

ART. 4. (*a*) A vessel, which from any accident is not under command, shall carry, at the same height as the white light mentioned in Art. 2 (*a*), where they can best be seen, and if a steam vessel in lieu of that light, two red lights, in a vertical line one over the other (see Fig. 5), not less than 6 feet apart, and of such a character as to be visible all around the horizon at a distance of at least 2 miles; and shall, by day, carry in a vertical line one over the other, not less than 6 feet apart, where they can best be seen, two black balls or shapes, each 2 feet in diameter.

Vessels Laying Telegraph Cables

(*b*) A vessel employed in laying or picking up a telegraph cable shall carry in the same position as the white light mentioned in Art. 2 (*a*), and if a steam vessel, in lieu of that light, three lights in a vertical line one over the other not less than 6 feet apart. The highest and lowest of these lights shall be red, and the middle light shall be white (See Fig. 5), and they shall be of such a character as to be visible all around the horizon, at a distance of at least 2 miles. By day she shall carry in a vertical line, one over the other, not less than 6 feet apart, where they can best be seen, three shapes not less than 2 feet in diameter, of which the highest and lowest shall be globular in shape and red in color, and the middle one diamond in shape and white.

When to Carry Side Lights

(*c*) The vessels referred to in this article, when not making way through the water, shall not carry the side lights, but when making way shall carry them.

(*d*) The lights and shapes required to be shown by this article are to be taken by other vessels as signals that the vessel showing them is not under command and cannot, therefore, get out of the way.

These signals are not signals of vessels in distress and requiring assistance. Such signals are contained in Art. **17** (text).

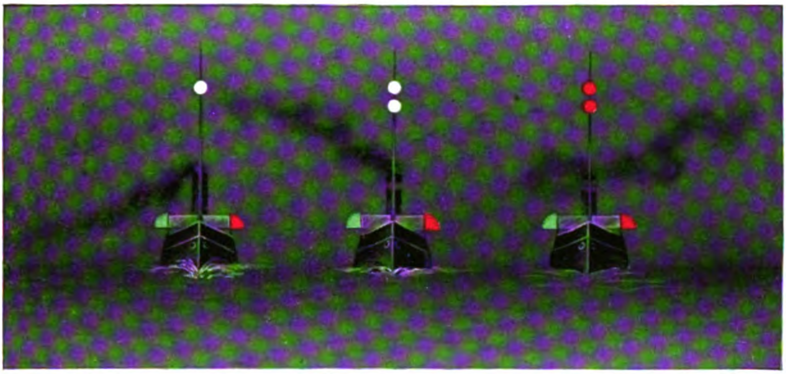
Lights for Sailing Vessels Under Way and Vessels Being Towed

ART. 5. A sailing vessel under way and any vessel being towed shall carry the same lights as are prescribed by Art. 2 for a steam vessel under way, with the exception of the white lights mentioned therein, which they shall never carry. (See Fig. 5.)

Portable Lights for Small Vessels Under Way

ART. 6. Whenever, as in the case of small vessels under way during bad weather, the green and red side lights cannot be fixed, these lights shall be kept at hand, lighted and ready for use; and shall, on the approach of or to other vessels, be exhibited on their respective sides in sufficient time to prevent collision, in such manner as to make them most visible, and so that the green light shall not be seen on the port

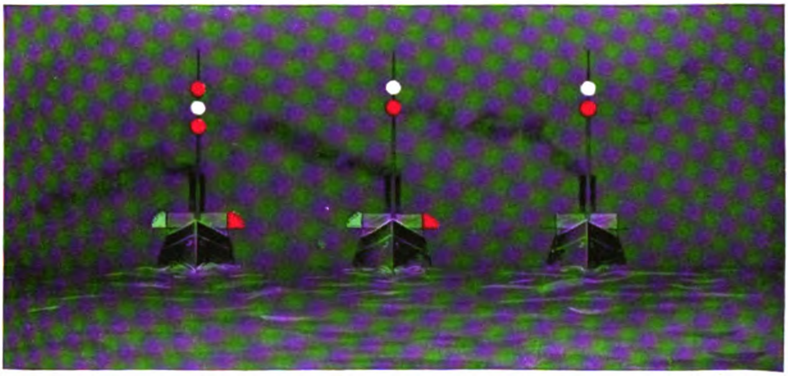
PRINCIPAL NIGHT SIGNALS



ART. 2
Steamer Under Way

ART. 3
Steamer Towing

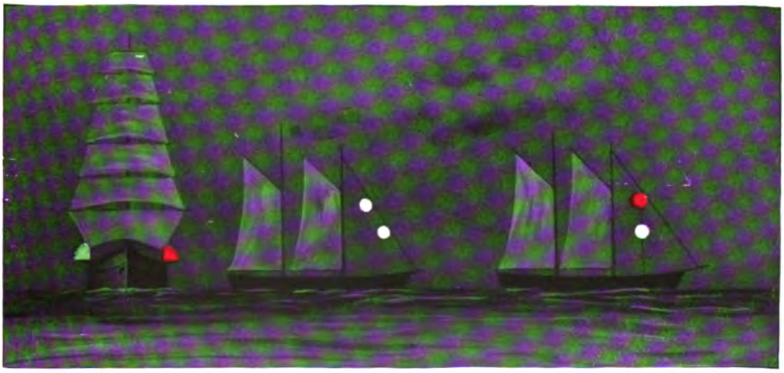
ART. 4 (*a*)
Not Under Control



ART. 4 (*b*)
Cable Ship

ART. 8
Steam Pilot Boat
On Duty and Under
Way

ART. 8
Steam Pilot Boat
On Duty, but at
Anchor



ART. 5
Sailing Vessel
Under Way

ART. 9 (*b*)
Fishing Vessel,
Drift Nets

ART. 9 (*c*)
Fishing Vessel,
Trawling

FIG. 5

§ 18 28129

side nor the red light on the starboard side, nor, if practicable, more than two points abaft the beam on their respective sides.

To make the use of these portable lights more certain and easy, the lanterns containing them shall each be painted outside with the color of the light they respectively contain, and shall be provided with proper screens.

Lights for Vessels Under 40 Tons

ART. 7. Steam vessels of less than 40 tons and vessels under oars or sails of less than 20 tons gross tonnage, respectively, ***and rowing boats***, when under way, shall not be obliged to carry the lights mentioned in Art. 2 (*a*), (*b*), and (*c*); but if they do not carry them, they shall be provided with the following lights:

First. Steam vessels of less than 40 tons shall carry:

(*a*) In the fore part of the vessel, or on or in front of the funnel, where it can best be seen, and at a height above the gunwale of not less than 9 feet, a bright white light, constructed and fixed as prescribed in Art. 2 (*a*), and of such a character as to be visible at a distance of at least 2 miles.

(*b*) Green and red side lights, constructed and fixed as prescribed in Art. 2 (*b*) and (*c*), and of such a character as to be visible at a distance of at least 1 mile, or a combined lantern showing a green light and a red light from right ahead to two points abaft the beam on their respective sides. Such lantern shall be carried not less than 3 feet below the white light.

Second. Small steam boats, such as are carried by seagoing vessels, may carry the white light at a less height than 9 feet above the gunwale, but it shall be carried above the combined lantern mentioned in (*b*) of the first subdivision.

Third. Vessels under oars or sails of less than 20 tons shall have ready at hand a lantern with a green glass on one side and a red glass on the other, which, on the approach of or to other vessels, shall be exhibited in sufficient time to prevent collision, so that the green light shall not be seen on the port side nor the red light on the starboard side.

Fourth. Rowing boats, whether under oars or sail, shall have ready at hand a lantern showing a white light, which shall be temporarily exhibited in sufficient time to prevent collision.

The vessels referred to in this article shall not be obliged to carry the lights prescribed by Art. 4 (*a*) and Art. 11, last paragraph.

Lights for Pilot Vessels

ART. 8. Pilot vessels when engaged on their station on pilotage duty shall not show the lights required for other vessels, but shall carry a white light at the masthead, visible all around the horizon, and shall also exhibit a flare-up light or flare-up lights at short intervals, which shall never exceed 15 minutes.

On the near approach of or to other vessels they shall have their side lights lighted, ready for use, and shall flash or show them at short intervals, to indicate the direction in which they are heading, but the green light shall not be shown on the port side, nor the red light on the starboard side.

A pilot vessel of such a class as to be obliged to go alongside of a vessel to put a pilot on board may show the white light instead of carrying it at the masthead, and may, instead of the colored lights above mentioned, have at hand, ready for use, a lantern with a green glass on the one side and a red glass on the other, to be used as prescribed above.

Pilot vessels when not engaged on their station on pilotage duty shall carry lights similar to those of other vessels of their tonnage.

A steam pilot vessel, when engaged on her station on pilotage duty and in waters of the United States, and not at anchor, shall, in addition to the lights required for all pilot boats, carry at a distance of 8 feet below her white masthead light a red light, visible all around the horizon and of such a character as to be visible on a dark night with a clear atmosphere at a distance of at least 2 miles, and also the colored side lights required to be carried by vessels when under way. (See Fig. 5.)

When engaged on her station on pilotage duty and in waters of the United States, and at anchor, she shall carry in addition to the lights required for all pilot boats the red light above mentioned, but not the colored side lights. (See Fig. 5.) When not engaged on her station on pilotage duty, she shall carry the same lights as other steam vessels.

Lights for Fishing Vessels

ART. 9. (Art. 9, Act of August 19, 1890, was repealed by Act of May 28, 1894, and article 10, Act of March 3, 1885, was reenacted in part as follows, by Act of August 13, 1894, and is reproduced here as article 9. It will be the object of further consideration by the Maritime Powers.)

Fishing vessels of less than 20 tons net registered tonnage, when under way and when not having their nets, trawls, dredges, or lines in the water, shall not be obliged to carry the colored side lights; but every such boat and vessel shall in lieu thereof have ready at hand a lantern with a green glass on the one side and a red glass on the other side, and on approaching to or being approached by another vessel, such a lantern shall be exhibited in sufficient time to prevent collision, so that the green light shall not be seen on the port side nor the red light on the starboard side.

The following portion of this article applies only to fishing vessels and boats when in the sea off the coast of Europe lying north of Cape Finisterre:

(*a*) All fishing vessels and fishing boats of 20 tons net registered tonnage or upwards, when under way and when not having their nets, trawls, dredges, or lines in the water, shall carry and show the same lights as other vessels under way.

Lights for Vessels Fishing With Drift Nets

(*b*) All vessels when engaged in fishing with drift nets shall exhibit two white lights from any part of the vessel where they can be best seen. (See Fig. 5.) Such lights shall be placed so that the vertical distance between them shall be not less than 6 feet and not more than 10 feet, and so that the horizontal distance between them, measured in a line with the keel of the vessel, shall be not less than 5 feet and not more than 10 feet. The lower of these two lights shall be the more forward, and both of them shall be of such a character and contained in lanterns of such construction as to show all around the horizon, on a dark night, with a clear atmosphere, for a distance of not less than 3 miles.

Lights for Vessels Engaged in Trawling

(*c*) All vessels when trawling, dredging, or fishing with any kind of drag nets shall exhibit, from some part of the vessel where they can be best seen, two lights. One of these lights shall be red and the other shall be white. The red light shall be above the white light, and shall be at a vertical distance from it of not less than 6 feet and not more than 12 feet; and the horizontal distance between them, if any, shall not be more than 10 feet. (See Fig. 5.) These two lights shall be of such a character and contained in lanterns of such construction as to be visible all around the horizon, on a dark night, with a clear atmosphere, the white light to a distance of not less than 3 miles and the red light of not less than 2 miles.

Lights for Vessels Engaged in Line Fishing

(*d*) A vessel employed in line fishing with her lines out shall carry the same lights as a vessel when engaged in fishing with drift nets.

(*e*) If a vessel, when fishing with a trawl, dredge, or any kind of drag net, becomes stationary in consequence of her gear getting fast to a rock or other obstruction, she shall show the light and make the fog signal for a vessel at anchor.

(*f*) Fishing vessels and open boats may at any time use a flare-up in addition to the lights which they are by this article required to carry and show. All flare-up lights exhibited by a vessel when trawling, dredging, or fishing with any kind of drag net, shall be shown at the after part of the vessel, excepting that if the vessel is hanging by the stern to her trawl, dredge, or drag net they shall be exhibited from the bow.

(*g*) Every fishing vessel and every open boat when at anchor between sunset and sunrise shall exhibit a white light, visible all around the horizon at a distance of at least 1 mile.

Fog Signals for Fishing Vessels

(*h*) In a fog, a drift-net vessel attached to her nets, and a vessel when trawling, dredging, or fishing with any kind of drag net, and a vessel employed in line fishing with her lines out, shall, at intervals of not more than 2 minutes, make a blast with her fog horn and ring her bell alternately.

Light for Vessel Being Overtaken

ART. 10. A vessel which is being overtaken by another shall show from her stern to such last-mentioned vessel a white light or a flare-up light.

The white light required to be shown by this article may be fixed and carried in a lantern, but in such case the lantern shall be so constructed, fitted, and screened that it shall throw an unbroken light over an arc of the horizon of twelve points of the compass, namely, for six points from right aft on each side of the vessel, so as to be visible at a distance of at least 1 mile. Such light shall be carried as nearly as practicable on the same level as the side lights.

Lights for Vessels at Anchor

ART. 11. A vessel under 150 feet in length, when at anchor, shall carry forwards, where it can best be seen, but at a height not exceeding 20 feet above the hull, a white light in a lantern so constructed as to show a clear, uniform, and unbroken light visible all around the horizon at a distance of at least 1 mile.

A vessel of 150 feet, or upwards, in length, when at anchor, shall carry in the forward part of the vessel, at a height of not less than 20 and not exceeding 40 feet above the hull, one such light, and at or near the stern of the vessel, and at such a height that it shall be not less than 15 feet lower than the forward light, another such light.

The length of a vessel shall be deemed to be the length appearing in her certificate of registry.

A vessel aground in or near a fairway shall carry the above light or lights and the two red lights prescribed by Art. 4 (*a*).

Signals for Attracting Attention

ART. 12. Every vessel may, if necessary in order to attract attention, in addition to the lights which she is by these rules required to carry, show a flare-up light or use any detonating signal that cannot be mistaken for a distress signal.

Lights for Squadrons and Convoys

ART. 13. Nothing in these rules shall interfere with the operation of any special rules made by the government of any nation with respect to additional station and signal lights for two or more ships of war or for vessels sailing under convoy, or with the exhibition of recognition signals adopted by ship owners, which have been authorized by their respective governments and duly registered and published.

ART. 14. A steam vessel proceeding under sail only, but having her funnel up, shall carry in the daytime, forwards, where it can best be seen, one black ball or shape 2 feet in diameter.

FOG SIGNALS

Fog Signals for Vessels Under Way

ART. 15. All signals prescribed by this article for vessels under way shall be given:

1. By "steam vessels" on the whistle or siren.
2. By "sailing vessels or vessels towed" on the fog horn.

The words "prolonged blast" used in this article shall mean a blast of from 4 to 6 seconds' duration.

A steam vessel shall be provided with an efficient whistle or siren, sounded by steam or some substitute for steam, so placed that the sound may not be intercepted by any obstruction, and with an efficient fog horn, to be sounded by mechanical means, and also with an efficient bell. (In all cases where the rules require a bell to be used, a drum may be substituted on board Turkish vessels, or a gong where such articles are used on board small seagoing vessels.) A sailing vessel of 20 tons gross tonnage or upwards shall be provided with a similar fog horn and bell.

In fog, mist, falling snow, or heavy rainstorms, whether by day or night, the signals described in this article shall be used as follows, viz.:

(*a*) A steam vessel having way upon her shall sound, at intervals of not more than 2 minutes, a prolonged blast.

(*b*) A steam vessel under way, but stopped, and having no way upon her, shall sound, at intervals of not more than 2 minutes, two prolonged blasts, with an interval of about 1 second between them.

(*c*) A sailing vessel under way shall sound, at intervals of not more than 1 minute, when on the starboard tack one blast, when on the port tack two blasts in succession, and when with the wind abaft the beam three blasts in succession.

Fog Signals for Vessels at Anchor

(*d*) A vessel when at anchor shall, at intervals of not more than 1 minute, ring a bell rapidly for about 5 seconds.

Fog Signals for Vessels Towing and Being Towed

(*e*) A vessel, when towing a vessel employed in laying or in picking up a telegraph cable, and a vessel under way, which is unable to get out of the way of an approaching vessel through being not under command, or unable to maneuver as required by the rules, shall, instead of the signals prescribed in subdivisions (*a*) and (*c*) of this article, at intervals of not more than 2 minutes, sound three blasts in succession, namely: One prolonged blast followed by two short blasts. A vessel towed may give this signal and she shall not give any other.

Sailing vessels and boats of less than 20 tons gross tonnage shall not be obliged to give the above-mentioned signals, but, if they do not, they shall make some other efficient sound signal at intervals of not more than 1 minute.

Speed of Ships to be Moderated in Fog

ART. 16. Every vessel shall, in a fog, mist, falling snow, or heavy rainstorms, go at a moderate speed, having careful regard to the existing circumstances and conditions.

A steam vessel hearing, apparently forward of her beam, the fog signal of a vessel the position of which is not ascertained shall, so far as the circumstances of the case admit, stop her engines, and then navigate with caution until danger of collision is over.

STEERING AND SAILING RULES

Steering and Sailing Rules for Sailing Ships

Risk of collision can, when circumstances permit, be ascertained by carefully watching the compass bearing of an approaching vessel. If the bearing does not appreciably change, such risk should be deemed to exist.

ART. 17. When two sailing vessels are approaching each other, so as to involve risk of collision, one of them shall keep out of the way of the other, as follows, namely:

(*a*) A vessel that is running free shall keep out of the way of a vessel that is close-hauled.

(*b*) A vessel which is close-hauled on the port tack shall keep out of the way of a vessel which is close-hauled on the starboard tack.

(*c*) When both are running free, with the wind on different sides, the vessel which has the wind on the port side shall keep out of the way of the other.

(*d*) When both are running free, with the wind on the same side, the vessel which is to the windward shall keep out of the way of the vessel which is to leeward.

(*e*) A vessel which has the wind aft shall keep out of the way of the other vessel.

Two Steam Vessels Meeting End On

ART. 18. When two steam vessels are meeting end on, or nearly end on, so as to involve risk of collision, each shall alter her course to starboard, so that each may pass on the port side of the other.

This article only applies to cases where vessels are meeting end on, or nearly end on, in such a manner as to involve risk of collision, and does not apply to two vessels which must, if both keep on their respective courses, pass clear of each other.

The only cases to which it does apply are when each of the two vessels is end on, or nearly end on, to the other; in other words, to cases in which, by day, each vessel sees the masts of the other in a

line, or nearly in a line, with her own; and by night to cases in which each vessel is in such a position as to see both the side lights of the other.

It does not apply by day to cases in which a vessel sees another ahead crossing her own course; or by night to cases where the red light of one vessel is opposed to the red light of the other, or where the green light of one vessel is opposed to the green light of the other, or where a red light without a green light, or a green light without a red light, is seen ahead, or where both green and red lights are seen anywhere but ahead.

Two Steam Vessels Crossing

ART. 19. When two steam vessels are crossing, so as to involve risk of collision, the vessel which has the other on her own starboard side shall keep out of the way of the other.

Steam and Sailing Vessels Meeting

ART. 20. When a steam vessel and a sailing vessel are proceeding in such directions as to involve risk of collision, the steam vessel shall keep out of the way of the sailing vessel.

One Vessel to Keep Out of the Way

ART. 21. Where, by any of these rules, one of two vessels is to keep out of the way, the other shall keep her course and speed.

NOTE.—When, in consequence of thick weather or other causes, such vessel finds herself so close that collision cannot be avoided by the action of the giving-way vessel alone, she also shall take such action as will best aid to avert collision (see Arts. 27 and 29).

Vessels Avoid Crossing Ahead

ART. 22. Every vessel which is directed by these rules to keep out of the way of another vessel shall, if the circumstances of the case admit, avoid crossing ahead of the other.

Steamer to Slacken Speed if Necessary

ART. 23. Every steam vessel which is directed by these rules to keep out of the way of another shall, on approaching her, if necessary, slacken her speed or stop or reverse.

Vessel Overtaking Another

ART. 24. Notwithstanding anything contained in these rules every vessel overtaking any other shall keep out of the way of the overtaken vessel.

Every vessel coming up with another vessel from any direction more than two points abaft her beam, that is, in such a position, with reference to the vessel which she is overtaking, that at night she would be unable to see either of that vessel's side lights, shall be deemed to be an overtaking vessel; and no subsequent alteration of the bearing between the two vessels shall make the overtaking vessel a crossing vessel within the meaning of these rules, or relieve her of the duty of keeping clear of the overtaken vessel until she is finally past and clear.

As by day the overtaking vessel cannot always know with certainty whether she is forward of or abaft this direction from the other vessel, she should, if in doubt, assume that she is an overtaking vessel and keep out of the way.

ART. 25. In narrow channels every steam vessel shall, when it is safe and practicable, keep to that side of the fairway or mid-channel which lies on the starboard side of such vessel.

Sailing Vessels to Keep Out of Way of Fishing Boats, Etc.

ART. 26. Sailing vessels under way shall keep out of the way of sailing vessels or boats fishing with nets, or lines, or trawls. This rule shall not give to any vessel or boat engaged in fishing the right of obstructing a fairway used by vessels other than fishing vessels or boats.

Special Circumstances Rendering Departure From Rules Necessary

ART. 27. In obeying and construing these rules, due regard shall be had to all dangers of navigation and collision, and to any special circumstances which may render a departure from the above rules necessary in order to avoid immediate danger.

SOUND SIGNALS FOR VESSELS IN SIGHT OF ONE ANOTHER

ART. 28. The words "short blast" used in this article shall mean a blast of about 1 second's duration.

When vessels are in sight of one another, a steam vessel under way, in taking any course authorized or required by these rules, shall indicate that course by the following signals on her whistle or siren, namely:

One short blast to mean, "I am directing my course to starboard."

Two short blasts to mean, "I am directing my course to port."

Three short blasts to mean, "My engines are going at full speed astern."

NO VESSEL, UNDER ANY CIRCUMSTANCES, TO NEGLECT PROPER PRECAUTIONS

ART. 29. Nothing in these rules shall exonerate any vessel, or the owner or master or crew thereof, from the consequences of any neglect to carry lights or signals, or of any neglect to keep a proper lookout, or of the neglect of any precaution that may be required by the ordinary practice of seamen or by the special circumstances of the case.

RESERVATION OF RULES FOR HARBORS AND INLAND NAVIGATION

ART. 30. Nothing in these rules shall interfere with the operation of a special rule, duly made by local authority, relative to the navigation of any harbor, river, or inland waters.

CONFLICTING LAWS REPEALED

SEC. 2. That all laws or parts of laws inconsistent with the foregoing regulations for preventing collisions at sea for the navigation of all public and private vessels of the United States upon the high seas, and in all waters connected therewith navigable by seagoing vessels, are hereby repealed.

22. Remarks.—The foregoing rules to prevent collisions at sea should be carefully studied. Questions on these rules play an important part in the examination of applicants for license. In order to answer questions relating to these rules intelligently and unhesitatingly, it is suggested that before going up for examination the applicant make a suitable number of small cardboard models of ships, and place on them, in proper positions, colored marks to represent the various lights carried by ships at night. Then, by arranging these models in every conceivable position and consulting the rules appertaining to each position, a few hours' study will be of considerably more value than any number of questions asked and answered.

It should be noted that the rules just given are the revised international rules, applicable to navigation on the high seas. For the navigation of rivers, harbors, and inland waters of the United States, separate rules have been drawn up; these are printed in Department Circular No. 88, and may be obtained by applying to the Bureau of Navigation, Department of Commerce and Labor, Washington, D. C. Again, for the Great Lakes and their connecting and tributary waters, another set of rules has been prepared. These rules are known as Pilot Rules for the Great Lakes.

DUTY TO STAY BY AFTER COLLISION

23. An Act in Regard to Collision at Sea.—In every case of collision between two vessels, it shall be the duty of the master or person in charge of each vessel, if and so far as he can do so without serious danger to his own vessel, crew, and passengers (if any), to stay by the other vessel until he has ascertained that she has no need of further assistance, and to render to the other vessel, her master, crew, and passengers (if any), such assistance as may be practicable and as may be necessary in order to save them from any danger caused by the collision, and also to give to the master or person in charge of the other vessel the name of his own vessel and her port of registry, or the port or

place to which she belongs, and also the name of the ports and places from which and to which she is bound. If he fails so to do, and no reasonable cause for such failure is shown, the collision shall, in the absence of proof to the contrary, be deemed to have been caused by his wrongful act, neglect, or default.

24. Every master or person in charge of a United States vessel who fails, without reasonable cause, to render such assistance or give such information as aforesaid, shall be deemed guilty of a misdemeanor, and shall be liable to a penalty of one thousand dollars, or imprisonment for a term not exceeding 2 years; and for the above sum the vessel shall be liable and may be seized and proceeded against by process in any district court of the United States by any person; one half such sum to be payable to the informer and the other half to the United States.

THE LIFE-SAVING SERVICE

25. The following information and instructions to mariners are furnished by the United States Life-Saving Service. The mariner should make himself thoroughly conversant with all the details, so as to be able to give intelligent and satisfactory answers to questions when examined on this subject.

26. Life-saving stations, life-boat stations, and houses of refuge are located on the Atlantic and Pacific seaboards of the United States, the Gulf of Mexico, and the Lake Coasts.

All stations on the Atlantic Coast from the eastern extremity of the state of Maine to Cape Fear, North Carolina, are manned annually by crews of experienced surfmen, from September 1 to May 1, following. On the Pacific Coast they are open and manned the year round, with the exception of the station at Cape Arago, which depends on volunteer effort from the neighboring people in case of shipwreck.

All life-saving and life-boat stations are fully supplied with boats, wreck guns, beach apparatus, restoratives, etc. In Fig. 6 is shown a typical life-saving station house, with surf boat resting in its carriage on the boat wagon used to transport the boat to any desired point of the beach.

Houses of refuge are supplied with boats, provisions, and restoratives, but are not manned by crews; a keeper, however, resides in each throughout the year. After every storm, the keeper is required to make extended excursions along the coast, with a view of ascertaining whether any

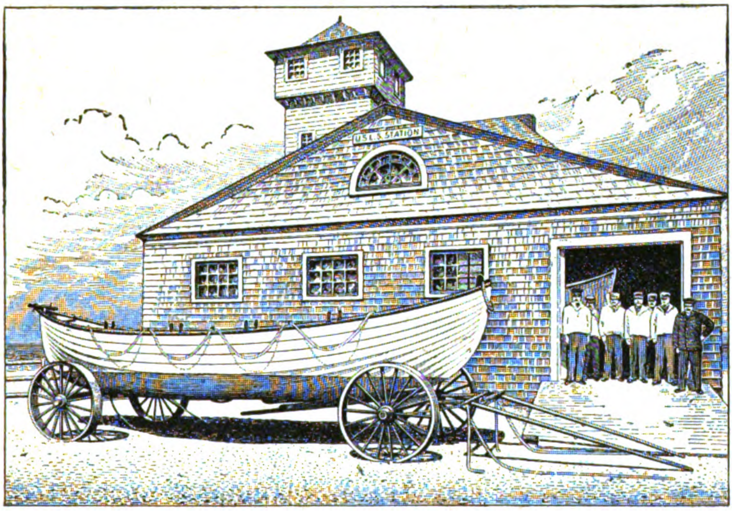


Fig. 6

shipwreck has occurred and finding and succoring any persons that may have been cast ashore.

Houses of refuge are located exclusively on the Florida Coast, where the requirements of relief are widely different from those of any other portion of the seaboard.

Most of the life-saving and life-boat stations are provided with the International Code of Signals, and vessels can, by opening communication, be reported; or can obtain the latitude and longitude of the station, where determined; or can obtain information as to the weather probabilities in most

cases; or, if crippled or disabled, a steam tug or revenue cutter will be telegraphed for, where facilities for telegraphing exist, to the nearest port, when requested.

All services are performed by the life-saving crews without other compensation than their wages from the government.

Destitute seafarers are provided with food and lodging at the nearest station by the government as long as necessarily detained by the circumstances of shipwreck.

The station crews patrol the beach from 2 to 4 miles each side of their stations four times between sunset and sunrise, and if the weather is foggy, the patrol is continued through the day.

Each patrolman carries Coston signals. On discovering a vessel standing into danger, he ignites one of them, which emits a brilliant *red flame* of about 2 minutes' duration, to warn her off; or, should a vessel be ashore, to let her crew know that they are discovered and that assistance is at hand.

If the vessel is not discovered by the patrol immediately after striking, rockets or flare-up lights should be burned; or, if the weather is foggy, guns should be fired to attract attention, as the patrolman may be some distance away at the other end of his beat.

Masters are particularly cautioned, if they should be driven ashore anywhere in the neighborhood of the stations, especially on any of the sandy coasts where there is not much danger of vessels breaking up immediately, to remain on board until assistance arrives, and under no circumstances should they attempt to land through the surf in their own boats until the last hope of assistance from the shore has vanished. Often, when it is comparatively smooth at sea, a dangerous surf is running that is not perceptible 400 yards off shore, and the surf when viewed from a vessel never appears as dangerous as it is. Many lives have been unnecessarily lost by the crews of stranded vessels being thus deceived and attempting to land in the ship's boats.

The difficulties of rescue by operations from the shore are greatly increased in cases where the anchors are let go *after entering the breakers*, as is frequently done, and the chances of saving life correspondingly lessened.

27. Rescue With Life or Surf Boat.—The patrolman, after discovering your vessel ashore and burning a Coston signal, hastens to his station for assistance. If the use of a boat is practicable, either the large life boat is launched from its ways in the station and proceeds to the wreck by water, or the lighter surf boat is hauled overland to a point opposite the wreck and launched, as circumstances may require.

On the boat reaching your vessel, the directions and orders of the keeper (who always commands and steers the boat) should be implicitly obeyed. Any headlong rushing and crowding should be prevented, and the captain of the vessel should remain on board, to preserve order, until every other person has left.

Women, children, helpless persons, and passengers should be passed into the boat first. Goods or baggage will positively not be taken into the boat until all are landed. If any be passed in against the keeper's remonstrance, he is fully authorized to throw the same overboard.

28. Rescue With Breeches Buoy or Life Car. Should it be inexpedient to use either the life boat or the surf boat, recourse will be had to the wreck gun and beach

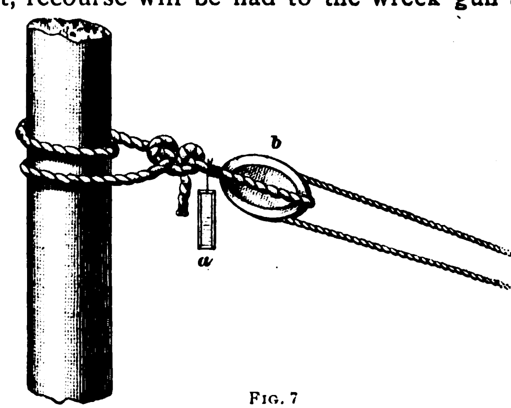


FIG. 7

apparatus for the rescue by the breeches buoy or life car. A shot with a small line attached will be fired across your vessel. Get hold of the line as soon as possible and haul

on board until you get a tail-block with a whip or endless line rove through it. This tail-block should be hauled on board as quickly as possible, to prevent the whip from drifting off with the set or fouling with wreckage, etc. Therefore, if you have been driven into the rigging, where only one or two men can work to advantage, cut the shot line and run it through some available block, such as the throat or peak halyard block, or any block that will afford a clear lead, or even between the ratlines, so that as many as possible may assist in hauling. Attached to the tail-block *b*, Fig. 7, will be a tally board *a* with the following directions, in English on one side and in French on the other: "Make the tail-block fast to the lower mast, well up. If masts are gone, then to the best place you can find. Cast off shot line. See that the rope in the blocks run free, and show signal to the shore." The instructions being complied with, the result will be as shown in Fig. 7. As soon as your signal is seen, a 3-inch hawser will be bent on to the whip and hauled off to your ship by the life-saving crew.

If circumstances permit, you can assist the life-saving crew by manning that part of the whip to which the hawser is bent and hauling with them.

29. When the end of the hawser reaches the ship, a tally board will be found attached to it bearing the following directions, in English on one side and French on the other: "Make this hawser fast about 2 feet above the tail-block; see all clear and that the rope in the block runs free, and show signal to the shore." These instructions being obeyed, the result will be as shown in Fig. 8.

Take particular care that there are no turns of the whip line around the hawser. To prevent this, take the end of the hawser up between the parts of the whip before making it fast.

When the hawser is made fast, the whip cast off from the hawser, and your signal seen by the life-saving crew, they will haul the hawser taut and by means of the whip will haul off to your ship a breeches buoy *d*, Fig. 9, suspended from a traveler block *c*, or a life car from rings, running on the

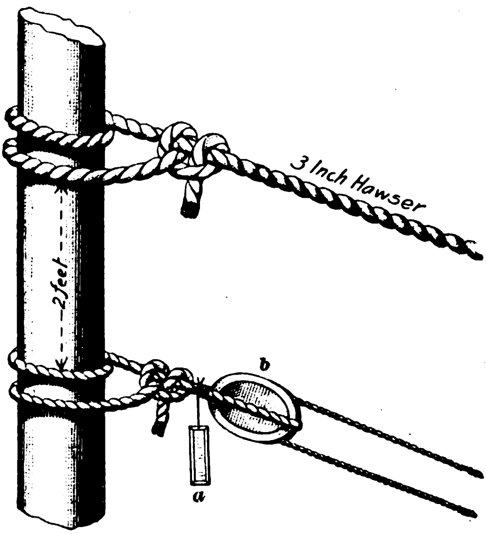


FIG. 8

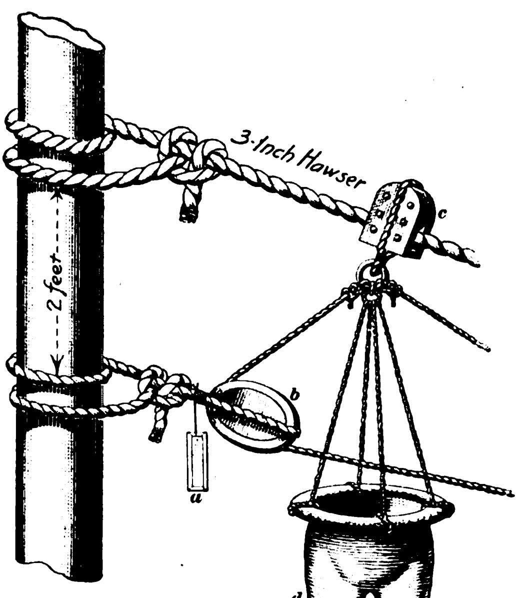


FIG. 9

hawser. Fig. 9 illustrates the apparatus rigged with the breeches buoy hauled off to the ship.

If the breeches buoy is sent, let one man immediately get into it, thrusting his legs through the breeches; if the life car, remove the hatch, place as many persons into it as it will hold (four or six), and secure the hatch on the outside by the hatch bar and hook. Then signal as before, and the buoy or the car will be hauled ashore. This will be repeated until all are landed. On the last trip of the life car, the hatch must be secured by the inside hatch bar.

In many instances, two men can be landed in the breeches buoy at the same time by each putting a leg through a leg of the breeches and holding on to the lifts of the buoy.

Children, when brought ashore by the buoy, should be either in the arms of older persons or securely lashed to the buoy. Women and children should be landed first.

The gun used for firing the line toward a stranded ship is a small bronze cannon weighing less than 200 pounds, and is capable of carrying the line a distance exceeding $\frac{3}{4}$ mile. In Fig. 10 the breeches buoy is shown in operation, carrying a man ashore from a stranded vessel.

30. In signaling as directed in the foregoing instructions, if in the daytime, let one man separate himself from the rest and swing his hat, a handkerchief, or his hand; if at night, the showing of a light and concealing it once or twice, will be understood; and like signals will be made from the shore.

Circumstances may arise, owing to the strength of the current or set, or the danger of the wreck breaking up immediately, when it would be impossible to send off the hawser. In such a case, a breeches buoy or life car will be hauled off by the whip, or sent off to you by the shot line, and you will be hauled ashore through the surf.

If your vessel is stranded during the night and discovered by the patrolman, which you will know by his burning a brilliant red light, keep a sharp lookout for signs of the arrival of the life-saving crew abreast of your vessel.

From 1 to 4 hours may intervene between the burning of the light and their arrival, as the patrolman will have to return to his station, perhaps 3 or 4 miles distant, and the life-saving crew draw the apparatus or surf boat through the sand or over bad roads to where your vessel is stranded.

Lights on the beach will indicate their arrival, and the sound of cannon firing from the shore may be taken as evidence that a line has been fired across your vessel. Therefore, on hearing the cannon, make a careful search aloft, fore and aft, for the shot line, for it is almost certain to be there. Though the movements of the life-saving crew may not be perceptible to you, owing to the darkness, your

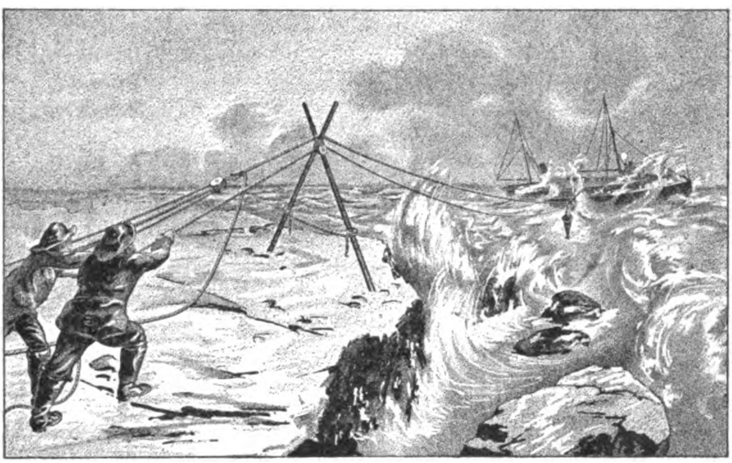


FIG. 10

ship will be a good mark for the men experienced in the use of the wreck gun, and the first shot seldom fails.

31. Life-Saving Signals.—The following signals, recommended by the late International Marine Conference for adoption by all institutions for saving life from wrecked vessels, have been adopted by the Life-Saving Service of the United States:

1. Upon the discovery of a wreck by night, the life-saving crew will burn a *red* pyrotechnic light or a *red* rocket to

signify: "You are seen; assistance will be given as soon as possible."

2. A *red* flag waved on shore by day, or a *red* light, *red* rocket, or *red* Roman candle displayed at night, will signify: "Haul away."

3. A *white* flag waved on shore by day, or a *white* light slowly swung back and forth, or a *white* rocket or *white* Roman candle fired by night will signify: "Slack away."

4. Two flags, a *white* and a *red*, waved at the same time on shore by day, or two lights, a *white* and a *red*, slowly swung at the same time, or a *blue* pyrotechnic light burned by night will signify: "Do not attempt to land in your own boats; it is impossible."

5. A man on shore beckoning by day, or two torches burning near together by night, will signify: "This is the best place to land."

Any of these signals may be answered from the vessel as follows: In the daytime, by waving a flag, a handkerchief, a hat, or even the hand; at night, by firing a rocket, a blue light, or a gun, or by showing a light over the ship's gunwale for a short time and then concealing it.

NOTE.—It is important that all signals from shore be answered by the ship at once, particularly at night. If signals are not answered within a reasonable time, the life-saving crew on the beach might infer that the crew of the stranded vessel have perished, and as a consequence may abandon their efforts at rescue.

32. Recapitulation.—Remain by the wreck until assistance arrives from shore, unless your vessel shows signs of immediately breaking up.

If not discovered immediately by the patrol, burn rockets, flare-ups, or other lights; or, if the weather is foggy, fire guns.

Take particular care that there are no turns of the whip line around the hawser before making the hawser fast.

Send the women, children, helpless persons, and passengers ashore first.

Make yourself thoroughly familiar with these instructions, and remember that on your coolness and strict attention to them will greatly depend the chances of success in bringing you and your people safely to land.

UNITED STATES BUOYAGE SYSTEM

33. In approaching a channel or fairway from seaward, red buoys with even numbers will be found on the starboard side of the channel, and must be kept to starboard when passing in. Black buoys with odd numbers will be found on the port side of the channel, and must be kept to port when passing in.

Buoys painted with red and black horizontal stripes indicate obstructions, with channel ways on either side of them, and may be passed on either side when entering.

Buoys painted with white and black perpendicular stripes are placed in the deepest part of the channel and should therefore be passed close by.

34. Other distinguishing marks on buoys may be used to mark particular spots; a description of these is given in the printed list of buoys issued by the United States Lighthouse Board. Perches, with balls, cages, etc., when placed on buoys, signify turning points in the channel, the color and number indicating on which side they shall be passed.

Different channels in the same bay, sound, river, or harbor are marked, as far as practicable, by different types of buoys. Principal channels are marked by nun buoys; secondary channels by can buoys; and minor channels by spar buoys. When there is only one channel, nun buoys, properly colored and numbered, are usually placed on the starboard side, and can buoys on the port side. Day beacons, stakes, and spindles (except such as are on the sides of channels, which will be colored like buoys) are constructed and distinguished with special reference to each locality, and particularly in regard to the background on which they are projected.

Wherever practicable, the towers, beacons, buoys, spindles, and all other aids to navigation are arranged in the buoy list of the Lighthouse Board in the order in which they are passed by vessels entering from seawards.

35. The navigator should keep in mind that the buoys in thoroughfares and passages between the islands along the

coast of Maine are numbered and colored for entering from the eastward.

Vessels approaching or passing United States lightships in thick, foggy weather will be warned of their proximity by the alternate ringing of a bell and sounding of a foghorn on board the lightship at intervals not exceeding 5 minutes.

TERMS AND SUGGESTIONS RELATING TO NAUTICO-LEGAL AFFAIRS

SHIP'S BUSINESS

36. A **certificate of registry** is a document signed by the registrar of the port to which the vessel belongs, and usually specifies the name and port of the vessel, her tonnage, the name of her master, particulars as to her origin, the names of her registered owners, etc.

37. A **charter party** is a document containing the agreement in chartering or obtaining the use of the vessel, and is given, usually, by either the owner, the agent, or the master, as the case may be.

38. A **manifest** is a document containing a list of the cargo and the names of its shippers and consignees. This is rendered necessary by customs procedure.

39. A **bill of lading** is a document of the loading of the cargo on board the vessel, and is usually signed by the agents of the vessel or by the master. Three or four copies of it are generally given.

40. A **protest** is a document prepared by a notary or by a consul representing the nationality of the vessel that has sustained loss or damage, or has been concerned in a loss or damage sustained by another vessel. In the protest, the master gives the particulars of the voyage and the circumstances that led to loss or disaster. This document is termed "protest" because it is the protest of the master against claim for damage or partial damage on the part of his vessel; it is usually sworn to by the master or chief officer,

and by a certain number of the crew. The protest should be entered within 24 hours after the ship arrives in port.

41. **Bottomry** is a bond given by the owner or master of the vessel on a foreign voyage, away from home, to defray expenses of the vessel, preventing her sale, and is a lien on the vessel. This document is usually at a high rate of premium—the law against usury not applying to it—depending on the casualty, and is not payable except on the safe arrival of the vessel. When a bond represents the vessel and cargo, it is termed a **bottomry and respondentia bond.**

42. A **bill of health** is a certificate stating that the vessel comes from a place where no contagious disease prevails, and that none of her crew at the time of her departure were infected with such disease.

43. **Articles** refer to the contract, or agreement, to which a seaman binds himself when joining a merchant ship. It includes various stipulations, such as the capacity in which the seaman is to serve, the amount of wages to be paid, and the character and probable duration of the intended voyage or engagement.

44. **General average** is a term that refers to a contribution made by parties concerned in a sea venture to cover a loss that has been sustained by voluntary sacrifice of the property of some of the parties by the master of the ship in the interest and for the benefit of all. It is called "general average" because the losses are recouped, or made good, by an average contribution from all parties concerned, who benefit by the sacrifice. Thus, if a ship is worth $100,000, the freight (or money earned by ship for carrying the cargo on the voyage) $25,000, and the cargo $50,000, and $10,000 worth of cargo is thrown overboard to lighten the ship, then this loss will not fall entirely on the owners of the cargo, but will be divided among the parties concerned on the principle of general average. The owners of the ship will pay four-sevenths (the proportion of the value of the ship to the value of ship, freight, and cargo), the owners of the freight will pay one-seventh, and the remaining two-sevenths

will fall on the owners of the cargo. The same principle holds good if the damage, or loss, happens to the ship itself; for instance, if spars, sails, or anchors are cut away to save the ship. The loss must be intentional, however; it does not apply to cargo washed overboard, ruined, or captured in time of war, but only to such losses as are incurred under pressure of immediate and unusual necessity.

45. Particular average is an allowance, or compensation, paid by an underwriter to the owner of cargo when damage or partial loss of goods shipped occurs during voyage, due to stress of weather or other perils of the sea. The compensation is made in the proportion that the average loss bears to the whole insurance. It applies to the ship itself as well as to the cargo.

46. Petty average refers to pilotage, anchorage, duty, etc. If these are incurred in the ordinary course of the voyage, they are not loss, but simply a part of the running expenses. If incurred under extraordinary conditions and for avoiding immediate dangers, however, they are termed petty average.

47. Freight or **freight money** is the amount paid for transportation of cargo.

48. Lay days are the number of days agreed on by the shipper and the master or the agent of a vessel (specified in charter party) for loading and discharging cargo, and beyond which a stipulated per diem (daily) demurrage is to be paid to the vessel. Sundays and holidays do not count, unless the term "running days" is inserted, in which case all days are included.

49. Demurrage refers to the detention of a vessel in port, in loading or unloading, beyond the time limit specified in her charter party; also to the compensation claimed for such delay, for which the charterer or his agent is responsible.

50. Jettison means the throwing overboard of goods or cargo in stress of weather, in order to lighten a vessel that is in danger or to prevent foundering.

51. Entering.—To **enter** a vessel, the master, upon arrival in port, must report in person to the custom officials and furnish them with a manifest setting forth all the details of the vessel's cargo, and to this paper he must take oath. The vessel shall not be considered as being regularly entered until the manifest has been formally accepted by the Collector of the port.

52. Clearance.—When a vessel is ready for sea, the custom officials must be provided with a detailed manifest of the ship's cargo, the accuracy of which is sworn to by the officer in command. Then, if the port charges of the vessel have been paid and her inward cargo is properly accounted for, the Collector will furnish the master with a **clearance document,** without which she must not attempt to leave port under penalty. American vessels under coasting license, permitting them to ply within certain districts in the United States, are exempted, provided they carry domestic cargo.

53. Barratry refers to any wilful and unlawful act committed by the master, officers, or crew of a ship contrary to their duty to the owners, whereby the latter sustain injury. Smuggling is barratry; so is the plundering or wilful destruction of cargo, trading with the enemy in time of war, and the avoidance of payment of dues, etc. There must be a wrongful intent to constitute the offense; mere error of judgment is not classed as barratry.

SUGGESTIONS TO MASTERS AND OFFICERS IN CASES OF MARITIME DISASTERS

54. Precaution and prudence are absolutely essential to insure success in any undertaking, and in no case do these qualities seem more necessary than for a commander of a ship having in his care valuable property and the lives of many of his fellow creatures. When an accident happens at sea and the vessel becomes disabled, all the resources and energy of the commander and his officers should be used to secure the safety of the lives and property in their care; and,

while the former is of first importance, the latter should by no means be overlooked. In many instances means have been improvised to repair damages that, apparently, were irreparable, and the vessel and cargo taken to their destination without material injury.

55. The causes of disasters and the means to be used to avert them are familiar to every competent navigator. But, after disaster has happened, the great question arises: What shall be done to reach the port of destination with as little expense and delay as possible?

The following suggestions, applying to such cases, issued by the Board of Underwriters, of New York, should be studied and consulted by officers and masters alike:

56. Disasters.—In case of disaster to vessels, and damage to their cargoes, occasioning their putting into ports of necessity, so much difficulty has, from time to time, occurred in relation to their averages and insurance, that these suggestions have been drawn up for the guidance of shipmasters and supercargoes, and have met the approbation of the underwriters of the principal cities.

In every case of disaster, the vessel must be repaired, if practicable, without a gross expenditure exceeding three-fourths the value of the vessel (that is, one-half affer deducting one-third for new), as valued in her policy of insurance, or estimated at the place of beginning her voyage from the United States.

If full repairs cannot be made at all, or without extraordinary expenses, temporary repairs must be put on the vessel, in order to complete the voyage; at its end, these repairs will be allowed in full, and the full repairs may be made after getting into a suitable port for repairing, at the expense of underwriters, as in other cases. In places where there are no opportunities of purchasing—or conveniences for putting on—copper without great expense, it is recommended to omit this expense until arrival at some of the considerable ports of Europe or the United States, when the same can be done more cheaply and better.

If spars are sprung, or sails or rigging injured, and cannot be readily replaced, or without great expense, every expedient should be applied that a practical seaman can improvise, in order to make the injured article serve until arrival at some port where the repairs can be completed at moderate expense. The repairs may then be made with advantage to all parties, without delay of the voyage or an extravagant expenditure of money, which is always more or less to the discredit of the shipmaster.

57. The Cargo.—In no case should the cargo be unladen without the clearest necessity. This is not only very expensive, but creates great delay, and is liable to end in serious damage to the cargo. The intelligent shipmaster will generally form his own opinion on this subject, and in doing so should consult competent persons who can gain nothing by his unloading the cargo. When unloading is concluded to be necessary, the shipmaster should be careful to stipulate against a charge of commission on the cargo for merely discharging, storing, and reloading, as no substantial responsibility is thereby incurred, and in most cases a charge of commission for such transactions is considered unreasonable, as it is no measure of compensation for service rendered. When allowed, it should never exceed $1\frac{1}{4}$ per cent. Should an unreasonable sum be required, or a high commission be demanded, the master can obviate the difficulty by hiring storeroom and retaining the entire control of the cargo himself. A proper charge for storage, and a regular commission for the general business of the ship under repair, will afford, in most instances, a fair and adequate remuneration for agency service. It is always proper to have suitable men employed to watch and take charge of a cargo, whose compensation will fall into an average, general or partial, and without any deduction; and so also any reasonable compensation to the merchant for his actual trouble, responsibility, and services will be justly chargeable and freely allowed. The difference between such charges and a commission on the whole cargo will be obvious to every shipmaster.

58. Sale of Vessels.—It should always be remembered that nothing but absolute necessity, or a cost to repair exceeding three-fourths the vessel's insured value, or value at her home port, can warrant a sale. It not infrequently happens that vessels are sold by masters abroad, simply because funds cannot be readily obtained to pay for repairs; and it has become a system in many places, of late years, to advertise for a loan on bottomry, and in case no offer for such loan is made within a few days, to sell the vessel. The fact that money cannot be had on bottomry to pay for the repairs she needs is no justification of sale. The right to sell is founded on a totally different principle. If the vessel is in a safe condition, and can remain so until her owners or their underwriters can be informed of the want of money, the master has no authority to sell; and any title he attempts to give will be invalid, and can be impeached whenever the vessel can be found within the United States. The master should communicate with the parties in interest, and await instructions—a sale of vessel is the last alternative. An unwarranted or hasty sale of vessel, or a sale prompted by selfish or careless advice, in most cases involves serious loss to owners, to merchants and shippers of cargo, as well as to underwriters, and cannot improve the shipmaster's reputation for prudence.

59. Stranded Vessels.—It too frequently occurs that when vessels are stranded on the seaboards of the United States the master abandons the property to the wreck commissioner, under the impression that he is bound to do so; in this he is mistaken. In all cases the master should keep the control of the property, employing the wreck commissioner when necessary for advice and information, and as one through whom he can procure all needful assistance; and it is the commissioner's duty to furnish assistance when required by a shipmaster in distress. The master's duty is to communicate with the owners or underwriters, by sending a special messenger to the nearest telegraph station or post office. At some of the smaller places on the United States

coasts the mails are sent off only once a week, and instances have occurred of letters being detained from unworthy motives. The master should in all cases use the most speedy method in the transmission of his advices, and, if necessary to insure despatch, he should send them by a messenger to the principal telegraph station and also to the post office on the nearest of the large mail routes.

60. Salvage.—In case the vessel shall be subject to salvage, it is proper always to have the vessel and cargo appraised at their value as brought in; and then the alternative adopted either to bond the cargo and vessel or to sell, as may be deemed necessary. The vessel, cargo, and freight may generally be pledged by bottomry, to relieve the vessel and cargo from the salvage charges; and this is expedient when funds cannot otherwise be obtained. But, if this cannot be done, and the vessel and cargo are not perishing so rapidly as to prevent communication with the home of the vessel, a postponement of the sale should always be applied for, until advice or relief can be had from the owners or insurers.

In any case of disaster to the vessel, if the cargo is saved, so that it can be sent on by any other vessel, the necessary extra freight will be reimbursed by the insurers or owners of cargo. When repairs are necessary for completing the voyage, and money cannot otherwise be obtained, a part of the cargo may be sold for that purpose; but this should only be done in urgent cases and when the cargo will bring reasonable prices. As what is sold must be accounted for at the price it would have brought had it arrived at its port of destination—which would frequently be much larger than could be obtained at the port of distress—the matter of selling should be carefully considered, and the prices at the port of destination should be ascertained before a decision is taken; and such cargo should be selected as would be likely to occasion least loss.

61. Port Wardens.—In foreign and even in some domestic ports, official persons, as port wardens, surveyors,

and the like, assume to *order* the cargo discharged, the vessel to be hove down, and the minute repairs to be made. It should always be borne in mind that the master is and ought to command his own vessel. He should exercise and rely on his own judgment, for which he is responsible, and on which his character and reputation rest. He may, if he is doubtful, take intelligent advice, and when measures are determined by him, he may have his own judgment confirmed by official persons or by others; but nothing will dispense with his exercising first his own honest and faithful judgment, showing, when required, the grounds of his judgment. Such officers as those just named must not be referred to as having authority sufficient to justify by their orders or certificates what they may recommend. As men having experience, they may give good advice, but the master should never loose sight of his own duty to select the best course and follow it. In these and all other cases of advice, certificates, and the like, the master should see that those who advise him have no private interest to be served in what they recommend.

62. Voyage Broken Up.—In case the voyage should inevitably be broken up by disasters and misfortunes, the master must carefully procure the proper protests and accounts of what is saved, and all of his expenditures on account. He should cause any balance of money, whether he supposes the vessel and cargo to have been abandoned or not, to be remitted in the surest way to his owners, consignors, or consignees of vessel or cargo. Such remittance will not at all affect the insurance, and will soonest reimburse some part of the loss to the owners of the property.

63. Jettison of Cargo.—Should it be necessary to jettison a part of the cargo, care should be taken to throw overboard the least valuable and most weighty parts, if time and other circumstances will permit the selection to be made.

64. Intelligence of Disasters.—A full account of every disaster should be sent by the master, without delay, to the owners, consignees, or insurers; and as the want of

intelligence is often injurious, as neither owner nor insurer can act or advise without information, duplicate accounts should be sent, if possible.

65. **Danger From Fire.**—It is as important that masters of vessels should take proper means for the prevention of disasters as that they should follow the right course after such disaster has occurred. The danger from fire has become of late years so great as to render necessary the utmost precaution against this destructive element, not only in the stowage of cargoes, but by keeping a full and competent watch on board vessels lying at anchor, or at the wharf. If possible, the sails should be unbent in all cases where the vessel may receive damage while lying at her dock from fire occurring in adjacent buildings.

In receiving or discharging cotton, hemp, oil, or other highly combustible cargo, care should be exercised to prevent the use of matches, pipes, or cigars, and, if practicable, to avoid the use of the galley or other fires on board the vessel. With a cargo that is liable to spontaneous combustion, the stowage of wet portions where they may heat and the careless use of oil are regarded as sources of great danger.

66. **Abandonment at Sea.**—In case of stress of weather at sea, by which the vessel becomes so disabled as to render her unseaworthy, the master should deliberate well before deciding to abandon his trust; but in case such course becomes imperative, the practice of scuttling or setting fire to the vessel before leaving is not recommended, as a ship sinking so rapidly as to compel her desertion will disappear soon enough without the use of such an expedient. The argument used in favor of burning, that unless this is done, disaster may be caused to other vessels, is not well founded, as should it happen (as it frequently does) that the ship does not sink, she can be more easily distinguished and collision avoided with her hull above the water than if scuttled or burned to the water's edge.

67. **Underwriters' Agents.**—In many ports, the underwriters have business men acting as agents, with whom

it is desirable that masters should consult in case of disaster. They are selected on the recommendation of merchants and commercial men at home, and their appointment is intended to facilitate the settlement of claims on underwriters arising out of disaster. Their advice and recommendation will be the safest protection of the upright and honorable shipmaster in every difficult case, and a conference with them will, of itself, be proof of the fairness of the shipmaster's intentions, as well as evidence of the wisdom of his measures. A neglect or refusal to consult the designated agent may lead to serious consequences.

68. Stowage of Cargo.—Shipmasters are also reminded that, as the vessel owner is responsible for all damage not caused by an accident of the voyage, they should be careful that the cargo is properly stowed, their intention being especially directed to see that it is well dunnaged, not only from the bottom, but from the sides as well, and that the weight is equally distributed. They should also do all in their power to prevent damage arising from *gas* created by the nature of the cargo, and from *sweat* or *steam*, which are not regarded as "perils of the sea."

69. Survey of Cargo.—If the cargo of a vessel upon arrival at her port of destination appears to be damaged, a survey should be called to prove the proper loading and stowage of the cargo, and that all necessary care had been taken to prevent it from injury during the voyage.

GUIDE TO APPLICANTS FOR MASTERS AND OFFICERS' LICENSE

70. Applicants intending to appear before any Board of United States Local Inspectors of Steam Vessels in order to secure a license as master or chief officer of deep-seagoing vessels should, in addition to working out various problems relating to the fixing of a ship's position at sea, be prepared to answer intelligently questions similar to the following. Although candidates for second and third mate are not

required to answer all of these questions, it is nevertheless good policy to be posted on the entire list, particularly questions relating to rules of the road. For requirements regarding length of sea service for different classes of license, consult the General Rules and Regulations prescribed by the Board of Supervising Inspectors.

1. What is latitude?
2. Explain the method of obtaining latitude by dead reckoning.
3. Explain how latitude is found by a meridian altitude of the sun.
4. Explain how latitude is found by ex-meridian altitudes of the sun.
5. How is latitude found by a meridian altitude of the moon?
6. How is latitude found by the pole star?
7. What is longitude?
8. How is longitude found by dead reckoning?
9. Explain the method of finding longitude by the chronometer.
10. How is latitude found by a meridian altitude of a star?
11. How do you find longitude by altitudes taken near noon?
12. Explain Sumner's method.
13. How do you find course and distance by chart?
14. Explain plane sailing.
15. Explain middle-latitude sailing.
16. Explain Mercator's sailing.
17. How do you detect an error in a quadrant or sextant?
18. How do you adjust a quadrant?
19. What are the three principal adjustments of the sextant?
20. What is polar distance?
21. What is zenith distance?
22. What is parallax?
23. What is refraction?
24. What is right ascension?
25. What is a radius?
26. What is the dip of the horizon?
27. What is equation of time?
28. What is apparent time?
29. What is mean time?
30. What is sidereal time?
31. What is semi-diameter?
32. What is a meridian?
33. What is the ecliptic?
34. What is an amplitude?
35. What is an angle?
36. What is an axis?
37. (*a*) What is an azimuth? (*b*) How do you find the error of the compass by the time-azimuth method? (*c*) How do you find the error of the compass by the altitude-azimuth method?
38. What is diurnal motion?
39. How are logarithms used?
40. What advantage is gained by the use of logarithms?
41. How do you find the error of the compass by an amplitude?
42. What causes the deviation of the compass?
43. How can you ascertain the amount of deviation?
44. How can you correct (compensate) a compass?
45. What do you understand by a Mercator's chart?
46. What is your method of

managing a steamer in a gale and heavy sea, the engines being under command?

47. Referring to the preceding question, what would you do in case the engines are disabled and the sails will not keep the ship under control?

48. Of what use have you found oil in heavy weather, and in what manner was it used?

49. Explain the construction and use of a drag or sea anchor?

50. Approaching a coast line in heavy weather, what precautions would you observe?

51. How would you steer a ship if the rudder were lost or damaged?

52. Referring to International Rules to prevent collisions at sea, when is a vessel considered to be: (*a*) a steam vessel? (*b*) a sailing vessel, (*c*) under way?

53. When the word "visible" in these Rules refers to lights, what does it mean in regard to night and atmosphere?

54. When are the lights in these Rules required to be shown?

55. Name the lights required on steam vessels under way.

56. Name the lights required on steam vessels towing other vessels.

57. (*a*) Name the special lights and day marks required by Art. 4 for a vessel not under command. (*b*) When is such a vessel to carry the side lights, as required by Art. 2, (*b*), (*c*), and (*d*)?

58. Name the lights required on sailing vessels under way.

59. Name the lights required on pilot vessels when on their station.

60. Name the lights required on a vessel that is being overtaken by another vessel.

61. Name the lights required on vessels at anchor.

62. When the words "short blast" are used in these Rules, how many seconds' duration is meant?

63. Give the whistle signal required: (*a*) when a steam vessel intends to direct her course to starboard; (*b*) when she intends to direct her course to port; (*c*) when her engines are going full speed astern.

64. Name the requirements of Art. 15, International Rules.

65. Give the fog signals required: (*a*) for a steam vessel having way upon her; (*b*) for a steam vessel under way, but stopped and having no way upon her.

66. Give fog signal: (*a*) for a sailing vessel under way; (*b*) for a steam vessel towing another vessel; (*c*) for a vessel being towed; (*d*) for a vessel at anchor.

67. A steam vessel hears apparently forward of her beam the fog signal of a vessel, the position of which is not ascertained; what shall be done?

68. When two sailing vessels are approaching each other so as to involve risk of collision, state which vessel shall keep out of the way of the other under the following conditions: (*a*) one vessel running free, the other close-hauled; (*b*) one vessel close-hauled on port tack, the other close-hauled on starboard tack; (*c*) both vessels running free, with wind on different sides; (*d*) both vessels running free, with wind on the same side.

69. When two steam vessels are meeting end on or nearly end on, so as to involve risk of collision, what is the duty of each?

70. When two steam vessels are crossing so as to involve risk of collision, what is the duty of each?

71. When a sailing vessel and a steam vessel are proceeding in such directions as to involve risk of collision, which vessel should keep out of the way of the other?

72. When, by these Rules, one vessel is required to keep out of the way, what is required of the other?

73. What are the requirements of Art. 22 in regard to one vessel crossing ahead of another?

74. When a vessel is overtaking another, what is she required to do by Art. 24?

75. In narrow channels, on which side of the fairway, when safe and practicable, is a steam vessel required to keep?

76. What are the distress signals: (*a*) in daytime? (*b*) at night?

77. What signals do you make for a pilot?

78. What motions has a cyclone, or hurricane?

79. How do you find the bearing of the storm center?

80. How would you maneuver to avoid the storm center?

81. What are the articles? State briefly what they contain.

82. What is the bill of health, and where is it obtained?

83. What is the official log book? What are you required to note in it?

84. What papers are necessary to clear the ship, and how would you do it?

85. What papers are necessary to enter the ship, and how would you do it?

86. What is general average?

87. What is particular average?

88. What is respondentia?

89. Describe a protest and state when and how it is used.

90. What is jettison?

91. What is barratry?

92. What is freight money?

93. What are lay days and demurrage?

94. Your ship puts into port in distress; what would you do first? After that, describe what action you would take.

95. How many flags are there in the International Code of Signals? What are their use?

96. In the event of a vessel stranding on a coast and help can be obtained from the life-saving station, state what procedure is necessary to land the crew in the life buoy and car, and give the signals to be exchanged by day and by night.

97. How do you mark a lead line?

98. How is the log line marked?

71. The problems to be worked out from examples furnished by the inspectors for various grades of license are about as follows:

Third Mate: Multiplication and division by logarithms; complete day's work, with compass courses given; problem in parallel sailing; problem to work latitude from a meridian altitude of the sun; to find Greenwich mean time from chronometer reading, the daily rate and error being given; problem to work longitude from a time-sight of the sun.

Second Mate: In addition to problems for third mate, to calculate compass error from an amplitude observation of the sun, the variation being known; to find course and distance between two given places by middle-latitude or Mercator's method.

Chief Mate: In addition to problems for third and second mates, to work out latitude from an ex-meridian observation of the sun and from an altitude of the pole star; to find compass error from azimuth observations of the sun; to calculate lines of position by Sumner's method, and to find true position of ship by plotting lines on chart furnished the applicant.

Master: In addition to problems for third, second, and chief mates, to work out longitude from sunset or sunrise sights; to work out latitude from a meridian altitude of a star; to work out longitude from a time-sight of a star.

72. Questions relating to stowage of cargo, and which are propounded to applicants for masters' license of inland waters, mates of ocean, coastwise, and inland waters, and to first- and second-class pilots, run about as follows:

1. What examination should be made of the hold of a vessel, and what would you consider necessary to do before taking aboard cargo?

2. How would you stow: (*a*) cases? (*b*) casks?

3. In what part of the hold should: (*a*) wet goods be stowed? (*b*) perishable goods be stowed? (*c*) heavy cargo, such as iron, copper, etc., be stowed?

4. What precautions should be taken with a cargo of cotton?

5. What precautions should be taken when loading and unloading, in regard to keeping the vessel upright and on an even keel?

6. What dangerous articles are prohibited as cargo on passenger steamers?

7. What is the lowest fire test of oil that may be used as stores on any steamer carrying passengers?

8. What is the lowest test of refined petroleum that vessels may carry as cargo when a special permit is obtained from local inspectors?

9. In case such permit is obtained, would you carry this oil in

any other place or places than designated in the permit?

10. In what part of a passenger steamer should baled hay, straw, or shavings, be stowed, and what should be done to protect such material from fire?

11. What precautions should be taken: (*a*) with a cargo of fruit? (*b*) with a cargo of coal?

12. With a cargo of bulk grain, what precautions should be taken to prevent shifting?

13. Explain contents of receipt that should be signed when receiving a cargo.

NOTE.—First- and second-class pilots, and mates of inland steamers, are usually required to answer all questions except 11, 12, and 13. Applicants for freight and towing class of vessels are usually required to answer all questions except 6, 7, 8, 9, and 10 For information on matters referred to in these questions consult General Rules and Regulations prescribed by the Board of Supervising Inspectors, Form 801.

THE HYDROMETER

73. The **hydrometer** is an instrument for measuring density or specific gravity.

74. The **specific gravity** of a solid is its weight compared with the weight of an equal volume of distilled water at the temperature of 39.2° F. Water is taken as the standard for solids and liquids, and air for gases. A cubic inch of sulphur weighs twice as much as a cubic inch of water; hence, its specific gravity is equal to 2.

75. The hydrometer used on board ship for obtaining the density of sea-water and the water in docks and rivers is shown in Fig. 11. This instrument consists of a glass tube, near the bottom of which are two bulbs. The lower and smaller bulb is loaded with mercury or shot, so as to cause the instrument to remain in a vertical position when placed in water. The upper bulb is filled with air, and its volume is such that the whole instrument is lighter than an equal volume of water. The scale on the tube reads from *0* downwards.

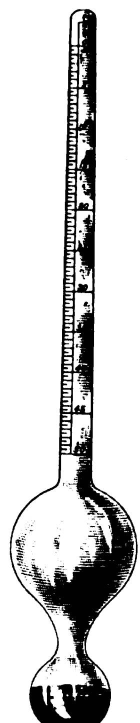


FIG. 11

76. When placed in distilled water, the instrument will sink to the division marked *0*, but in sea-water it will sink to

about the division marked *26*. In brackish water, it will sink to some point between these marks, according to the amount of salt the water contains. When finding the specific gravity of water with this instrument, the figure read off on the scale should be added to 1.000. The specific gravity, therefore, of ordinary sea-water is 1.026. In docks and rivers where fresh water enters, the specific gravity will vary between the limits of 1.000 and 1.026.

Since a body floats higher in salt water than in fresh water, it is evident that the saltness of the water in which a ship floats will have an important bearing on the draft of the ship. For instance, a ship may be loaded deeper in fresh or brackish water because she will "rise" a certain amount when she goes to sea. In England and a few other countries, the load line for seagoing vessels is regulated by law.

77. How to Find the Sea Draft When Draft of Ship in Harbor is Known, and Vice Versa.—If the specific gravity of the water at the loading place is obtained by a hydrometer, and the *draft* (or depth of ship) when loaded is known, a simple proportion will give the sea draft very nearly; also, when the sea draft is known, the draft in a dock or river can be found by the same proportion, which is as follows:

$$W : w = d : D$$

in which W = specific gravity of sea-water (= 1.026);
D = sea draft;
d = draft in harbor;
w = specific gravity of water in harbor.

EXAMPLE 1.—The specific gravity of the water in a harbor is 1.015 and the ship's draft is 23.5 feet. Find her draft in sea-water.

SOLUTION.—In this case, D is the quantity sought. Hence,

$$D = \frac{w \times d}{W} = \frac{1.015 \times 23.5}{1.026} = 23.2 \text{ ft., nearly. Ans.}$$

EXAMPLE 2.—At sea a ship draws 26.75 feet of water. What will be her draft in the dock at her destination, where the specific gravity of the water is 1.01?

SOLUTION.—In this case, d is the quantity sought. Hence,

$$d = \frac{W \times D}{w} = \frac{1.026 \times 26.75}{1.01} = 27.17 \text{ ft. Ans.}$$

Hours	Knots	Tenths	Courses	Wind	Leeway	Deviation	Barometer	Thermometer	Remarks
1									P. M.
2									
3									
4									
5									
6									
7									Variation allowed:
8									
9									
10									
11									
12									(Midnight)
1									A. M.
2									
3									
4									
5									
6									
7									Variation allowed:
8									
9									
10									
11									
12									(Noon)

Course Made Good	Distance Made Good	Dep.	D. Lat.	D. Long.	Latitude in	Longitude in	True Bearing and Distance
					Obs.:	Obs.:	
					D. R.	D. R.	

THE SHIP'S LOG BOOK

78. The official log book of a ship should contain a carefully prepared record of the day's work, or the details affecting the navigation of the ship. In this book should be entered the courses and distances run, with the amounts of leeway, variation, and deviation applicable to each, together with other data that have an important bearing on the safe navigation of the vessel. The position of the ship as determined by dead reckoning and astronomical observations is entered in separate columns. The log book may be made very simple or very elaborate; usually, each nation has its prescribed form of log book. At the end of each watch, the officer in charge of the deck records in the rough log, or scrap log, book the compass courses, the distance run, and other noteworthy data, all of which are subsequently transferred to the official log book. A simple and quite satisfactory form of log book for merchant ships is shown on the preceding page.

79. The entries to be made in the different columns are self-evident. The variation allowed is that taken from the chart. The column headed "Deviation" should be filled in from the table of deviation, previous to correcting the courses. The column headed True Bearing and Distance is filled in by computing (usually by Mercator's sailing) the course and distance between the position at noon, found by astronomical observations, and the place of destination or some point or danger lying near the intended track of the ship.

ABRIDGMENT OF

NAUTICAL ALMANAC

FOR 1899

JANUARY, 1899

At Greenwich Apparent Noon

I

Day of the Week	Day of the Month	The Sun's Apparent Right Ascension	Diff. for 1 Hr.	The Sun's Apparent Declination	Diff. for 1 Hr.	The Sun's Semi-Diameter	Equation of Time, to be Added to Apparent Time	Diff. for 1 Hr.
		h m s	s	° ′ ″	″	′ ″	m s	s
Sun.	1	18 47 28.68	11.03	S 23 0 14.0	+12.52	16 18.40	3 47.32	1.178
Mon.	2	18 51 53.43	11.02	22 54 59.9	13.66	16 18.39	4 15.43	1.165
Tues.	3	18 56 17.85	11.01	22 49 18.3	14.80	16 18.38	4 43.21	1.15[illegible]
Wed.	4	19 0 41.89	10.99	22 43 9.5	+15.93	16 18.36	5 10.63	1.134
Thur.	5	19 5 5.55	10.97	22 36 33.6	17.06	16 18.34	5 37.65	1.117
Fri.	6	19 9 28.77	10.95	22 29 30.7	18.17	16 18.31	6 4.24	1.099
Sat.	7	19 13 51.54	10.93	22 22 1.2	+19.28	16 18.28	6 30.38	1.079
Sun.	8	19 18 13.82	10.91	22 14 5.1	20.38	16 18.24	6 56.04	1.058
Mon.	9	19 22 35.59	10.89	22 5 42.9	21.47	16 18.20	7 21.18	1.036
Tues.	10	19 26 56.82	10.87	21 56 54.6	+22.54	16 18.16	7 45.78	1.013
Wed.	11	19 31 17.47	10.84	21 47 40.6	23.61	16 18.11	8 9.81	0.989
Thur.	12	19 35 37.53	10.82	21 38 1.2	24.66	16 18.06	8 33.25	0.964
Fri.	13	19 39 56.96	10.79	21 27 56.7	+25.70	16 18.00	8 56.06	0.937
Sat.	14	19 44 15.75	10.76	21 17 27.4	26.73	16 17.94	9 18.23	0.909
Sun.	15	19 48 33.86	10.74	21 6 33.5	27.74	16 17.88	9 39.72	0.881
Mon.	16	19 52 51.27	10.71	20 55 15.5	+28.74	16 17.81	10 0.52	0.852
Tues.	17	19 57 7.98	10.68	20 43 33.5	29.73	16 17.74	10 20.61	0.822
Wed.	18	20 1 23.95	10.65	20 31 28.1	30.70	16 17.67	10 39.97	0.791
Thur.	19	20 5 39.16	10.61	20 18 59.5	+31.66	16 17.59	10 58.58	0.760
Fri.	20	20 9 53.62	10.58	20 6 8.1	32.61	16 17.50	11 16.43	0.728
Sat.	21	20 14 7.29	10.55	19 52 54.2	33.54	16 17.41	11 33.50	0.695
Sun.	22	20 18 20.18	10.52	19 39 18.1	+34.45	16 17.32	11 49.79	0.662
Mon.	23	20 22 32.28	10.48	19 25 20.3	35.35	16 17.22	12 5.29	0.629
Tues.	24	20 26 43.58	10.45	19 11 1.0	36.24	16 17.11	12 19.99	0.596
Wed.	25	20 30 54.07	10.42	18 56 20.7	+37.11	16 17.00	12 33.89	0.562
Thur.	26	20 35 3.75	10.38	18 41 19.7	37.96	16 16.88	12 46.98	0.528
Fri.	27	20 39 12.62	10.35	18 25 58.3	38.80	16 16.75	12 59.26	0.495
Sat.	28	20 43 20.68	10.31	18 10 16.9	+39.63	16 16.62	13 10.72	0.461
Sun.	29	20 47 27.93	10.28	17 54 15.9	40.44	16 16.49	13 21.39	0.428
Mon.	30	20 51 34.37	10.25	17 37 55.7	41.23	16 16.35	13 31.25	0.394
Tues.	31	20 55 40.00	10.21	17 21 16.6	42.01	16 16.20	13 40.30	0.360
Wed.	32	20 59 44.82	10.18	S 17 4 19.1	+42.77	16 16.05	13 48.54	0.327

JANUARY, 1899

At Greenwich Mean Noon

II

Day of the Week	Day of the Month	The Sun's Apparent Declination	The Sun's Diff. for 1 Hour	Equation of Time, to be Subtracted From Mean Time	Diff. for 1 Hour	Sidereal Time, or Right Ascension of Mean Sun
		° ′ ″	″	m s	s	h m s
Sun.	1	S 23 0 14.9	+12.51	3 47.24	1.178	18 43 40.74
Mon.	2	22 55 0.9	13.65	4 15.34	1.164	18 47 37.30
Tues.	3	22 49 19.5	14.79	4 43.12	1.150	18 51 33.86
Wed.	4	22 43 10.9	+15.92	5 10.53	1.134	18 55 30.42
Thur.	5	22 36 35.2	17.05	5 37.54	1.117	18 59 26.97
Fri.	6	22 29 32.6	18.16	6 4.13	1.099	19 3 23.53
Sat.	7	22 22 3.3	+19.27	6 30.26	1.079	19 7 20.09
Sun.	8	22 14 7.5	20.37	6 55.91	1.058	19 11 16.65
Mon.	9	22 5 45.5	21.46	7 21.05	1.036	19 15 13.21
Tues.	10	21 56 57.6	+22.53	7 45.65	1.013	19 19 9.76
Wed.	11	21 47 43.9	23.60	8 9.67	0.989	19 23 6.32
Thur.	12	21 38 4.8	24.65	8 33.11	0.964	19 27 2.88
Fri.	13	21 28 0.6	+25.69	8 55.92	0.937	19 30 59.44
Sat.	14	21 17 31.6	26.72	9 18.09	0.909	19 34 55.99
Sun.	15	21 6 38.0	27.73	9 39.58	0.881	19 38 52.55
Mon.	16	20 55 20.3	+28.73	10 0.38	0.852	19 42 49.11
Tues.	17	20 43 38.7	29.72	10 20.47	0.822	19 46 45.66
Wed.	18	20 31 33.6	30.69	10 39.83	0.791	19 50 42.22
Thur.	19	20 19 5.4	+31.65	10 58.44	0.760	19 54 38.78
Fri.	20	20 6 14.2	32.60	11 16.29	0.728	19 58 35.34
Sat.	21	19 53 0.7	33.53	11 33.37	0.695	20 2 31.89
Sun.	22	19 39 24.9	+34.44	11 49.66	0.662	20 6 28.45
Mon.	23	19 25 27.4	35.34	12 5.16	0.629	20 10 25.01
Tues.	24	19 11 8.5	36.23	12 19.86	0.596	20 14 21.56
Wed.	25	18 56 28.5	+37.10	12 33.77	0.562	20 18 18.12
Thur.	26	18 41 27.8	37.95	12 46.86	0.529	20 22 14.68
Fri.	27	18 26 6.7	38.79	12 59.15	0.495	20 26 11.23
Sat.	28	18 10 25.7	+39.62	13 10.62	0.461	20 30 7.79
Sun.	29	17 54 25.0	40.43	13 21.29	0.428	20 34 4.34
Mon.	30	17 38 5.1	41.22	13 31.16	0.394	20 38 0.90
Tues.	31	17 21 26.3	42.00	13 40.21	0.360	20 41 57.46
Wed.	32	S 17 4 29.0	+42.76	13 48.46	0.327	20 45 54.01

JANUARY, 1899

Greenwich Mean Time

IV

Day of the Month	The Moon's							
	Semi-Diameter		Horizontal Parallax				Upper Transit	
	Noon	Midnight	Noon	Diff. for 1 Hour	Midnight	Diff. for 1 Hour	Meridian of Greenwich	Diff. for 1 Hour
	′ ″	′ ″	′ ″	″	′ ″	″	h m	m
1	14 50.6	14 53.4	54 21.9	+0.77	54 32.1	+0.94	15 44.1	1.72
2	14 56.8	15 0.7	54 44.5	1.12	54 59.0	1.30	16 25.4	1.73
3	15 5.3	15 10.4	55 15.7	1.48	55 34.5	1.66	17 7.7	1.80
4	15 16.1	15 22.4	55 55.5	+1.83	56 18.5	+1.99	17 52.2	1.91
5	15 29.1	15 36.3	56 43.3	2.14	57 9.8	2.26	18 39.9	2.08
6	15 43.9	15 51.7	57 37.6	2.35	58 6.3	2.41	19 32.1	2.28
7	15 59.7	16 7.5	58 35.4	+2.42	59 4.3	+2.38	20 29.2	2.48
8	16 15.2	16 22.4	59 32.5	2.28	59 59.1	2.12	21 30.9	2.64
9	16 29.1	16 34.9	60 23.4	1.90	60 44.7	1.62	22 35.2	2.70
10	16 39.7	16 43.2	61 2.3	+1.28	61 15.5	+0.90	23 39.6	2.64
11	16 45.6	16 46.5	61 24.0	+0.49	61 27.3	+0.06	♂	
12	16 45.9	16 44.0	61 25.4	−0.37	61 18.3	−0.79	0 41.4	2.50
13	16 40.8	16 36.3	61 6.4	−1.18	60 50.0	−1.52	1 39.3	2.33
14	16 30.8	16 24.5	60 29.9	1.81	60 6.6	2.04	2 33.3	2.18
15	16 17.5	16 10.0	59 40.9	2.21	59 13.5	2.32	3 24.2	2.07
16	16 2.3	15 54.6	58 45.3	−2.37	58 16.7	−2.37	4 13.1	2.01
17	15 46.8	15 39.3	57 48.3	2.33	57 20.8	2.25	5 1.2	2.00
18	15 32.2	15 25.4	56 54.4	2.13	56 29.5	2.00	5 49.2	2.01
19	15 19.1	15 13.3	56 6.3	−1.85	55 45.0	−1.69	6 38.0	2.05
20	15 8.0	15 3.3	55 25.7	1.52	55 8.5	1.35	7 27.7	2.09
21	14 59.2	14 55.6	54 53.3	1.18	54 40.1	1.02	8 18.1	2.11
22	14 52.5	14 50.0	54 28.8	−0.85	54 19.5	−0.70	9 8.8	2.10
23	14 47.9	14 46.3	54 11.9	0.56	54 6.0	0.42	9 58.7	2.06
24	14 45.1	14 44.4	54 1.7	0.30	53 58.9	−0.17	10 47.3	1.99
25	14 44.0	14 44.0	53 57.6	−0.06	53 57.6	+0.05	11 34.0	1.90
26	14 44.3	14 45.0	53 58.8	+0.15	54 1.3	0.26	12 18.7	1.82
27	14 46.0	14 47.4	54 5.0	0.36	54 10.0	0.46	13 1.7	1.76
28	14 49.1	14 51.1	54 16.2	+0.57	54 23.6	+0.68	13 43.4	1.73
29	14 53.5	14 56.3	54 32.4	0.79	54 42.6	0.90	14 24.8	1.72
30	14 59.4	15 3.0	54 54.2	1.02	55 7.3	1.15	15 6.5	1.76
31	15 7.0	15 11.4	55 21.9	1.28	55 38.1	1.42	15 49.6	1.84
32	15 16.3	15 21.5	55 56.0	+1.55	56 15.4	+1.68	16 35.1	1.96

JANUARY, 1899

Greenwich Mean Time

The Moon's Right Ascension and Declination

(Tuesday, 17)

Hour	Right Ascension	Diff. for 1 Minute	Declination	Diff. for 1 Minute
	h m s	s	° ′ ″	″
0	0 38 12.93	2.0964	N 9 50 17.2	13.042
1	0 40 18.71	2.0963	10 3 17.7	12.975
2	0 42 24.49	2.0963	10 16 14.2	12.907
3	0 44 30.27	2.0963	10 29 6.6	12.839
4	0 46 36.05	2.0963	10 41 54.9	12.769
5	0 48 41.83	2.0964	10 54 38.9	12.698
6	0 50 47.62	2.0966	11 7 18.7	12.627
7	0 52 53.42	2.0968	11 19 54.2	12.556
8	0 54 59.24	2.0971	11 32 25.4	12.483
9	0 57 5.07	2.0973	11 44 52.1	12.408
10	0 59 10.92	2.0977	11 57 14.4	12.334
11	1 1 16.79	2.0981	12 9 32.2	12.259
12	1 3 22.69	2.0985	12 21 45.5	12.183
13	1 5 28.61	2.0990	12 33 54.2	12.106
14	1 7 34.57	2.0996	12 45 58.2	12.027
15	1 9 40.56	2.1001	12 57 57.5	11.949
16	1 11 46.58	2.1007	13 9 52.1	11.871
17	1 13 52.64	2.1013	13 21 42.0	11.791
18	1 15 58.74	2.1021	13 33 27.0	11.709
19	1 18 4.89	2.1028	13 45 7.1	11.627
20	1 20 11.08	2.1036	13 56 42.3	11.546
21	1 22 17.32	2.1044	14 8 12.6	11.463
22	1 24 23.61	2.1053	14 19 37.9	11.379
23	1 26 29.96	2.1062	N 14 30 58.1	11.294

FEBRUARY, 1899

At Greenwich Apparent Noon

I

Day of the Week	Day of the Month	The Sun's Apparent Right Ascension	Diff. for 1 Hr.	Apparent Declination	Diff. for 1 Hr.	Semi-Diameter	Equation of Time, to be Added to Apparent Time	Diff. for 1 Hr.
		h m s	s	° ′ ″	″	′ ″	m s	s
Wed.	1	20 59 44.82	10.18	S 17 4 19.1	+42.77	16 16.05	13 48.54	0.327
Thur.	2	21 3 48.84	10.15	16 47 3.4	43.52	16 15.89	13 55.98	0.293
Fri.	3	21 7 52.05	10.11	16 29 30.2	44.25	16 15.73	14 2.62	0.260
Sat.	4	21 11 54.46	10.08	16 11 39.6	+44.96	16 15.57	14 8.46	0.227
Sun.	5	21 15 56.08	10.05	15 53 32.2	45.65	16 15.40	14 13.50	0.194
Mon.	6	21 19 56.89	10.01	15 35 8.4	46.33	16 15.23	14 17.75	0.161
Tues.	7	21 23 56.92	9.98	15 16 28.5	+46.98	16 15.05	14 21.22	0.128
Wed.	8	21 27 56.16	9.95	14 57 33.1	47.62	16 14.87	14 23.88	0.095
Thur.	9	21 31 54.59	9.91	14 38 22.6	48.24	16 14.69	14 25.76	0.062
Fri.	10	21 35 52.25	9.88	14 18 57.4	+48.85	16 14.51	14 26.87	0.029
Sat.	11	21 39 49.13	9.85	13 59 18.0	49.43	16 14.33	14 27.19	0.003
Sun.	12	21 43 45.24	9.82	13 39 24.8	50.00	16 14.14	14 26.74	0.035
Mon.	13	21 47 40.57	9.79	13 19 18.2	+50.55	16 13.95	14 25.53	0.066
Tues.	14	21 51 35.15	9.75	12 58 58.8	51.07	16 13.76	14 23.55	0.098
Wed.	15	21 55 28.97	9.72	12 38 26.8	51.58	16 13.56	14 20.83	0.129
Thur.	16	21 59 22.05	9.69	12 17 42.8	+52.07	16 13.36	14 17.36	0.160
Fri.	17	22 3 14.39	9.66	11 56 47.2	52.55	16 13.16	14 13.16	0.190
Sat.	18	22 7 6.02	9.63	11 35 40.3	53.01	16 12.96	14 8.25	0.220
Sun.	19	22 10 56.94	9.60	11 14 22.6	+53.45	16 12.75	14 2.63	0.249
Mon.	20	22 14 47.17	9.57	10 52 54.5	53.88	16 12.54	13 56.32	0.277
Tues.	21	22 18 36.72	9.55	10 31 16.4	54.29	16 12.33	13 49.34	0.304
Wed.	22	22 22 25.62	9.52	10 9 28.7	+54.68	16 12.11	13 41.71	0.331
Thur.	23	22 26 13.88	9.49	9 47 31.8	55.06	16 11.88	13 33.44	0.358
Fri.	24	22 30 1.52	9.47	9 25 26.0	55.42	16 11.66	13 24.55	0.384
Sat.	25	22 33 48.56	9.44	9 3 11.8	+55.76	16 11.43	13 15.06	0.408
Sun.	26	22 37 35.02	9.42	8 40 49.4	56.09	16 11.19	13 4.99	0.431
Mon.	27	22 41 20.92	9.40	8 18 19.3	56.41	16 10.95	12 54.37	0.454
Tues.	28	22 45 6.28	9.37	7 55 41.9	56.71	16 10.71	12 43.21	0.476
Wed.	29	22 48 51.13	9.35	S 7 32 57.5	+56.99	16 10.46	12 31.54	0.497

FEBRUARY, 1899

AT GREENWICH MEAN NOON

II

Day of the Week	Day of the Month	The Sun's Apparent Declination	The Sun's Diff. for 1 Hour	Equation of Time, to be Subtracted From Mean Time	Diff. for 1 Hour	Sidereal Time, or Right Ascension of Mean Sun
		° ′ ″	″	m s	s	h m s
Wed.	1	S 17 4 29.0	+42.76	13 48.46	0.327	20 45 54.01
Thur.	2	16 47 13.6	43.51	13 55.91	0.293	20 49 50.57
Fri.	3	16 29 40.6	44.24	14 2.56	0.260	20 53 47.12
Sat.	4	16 11 50.2	+44.95	14 8.41	0.227	20 57 43.68
Sun.	5	15 53 43.1	45.64	14 13.46	0.194	21 1 40.23
Mon.	6	15 35 19.5	46.32	14 17.72	0.161	21 5 36.79
Tues.	7	15 16 39.8	+46.97	14 21.19	0.128	21 9 33.34
Wed.	8	14 57 44.6	47.61	14 23.86	0.095	21 13 29.90
Thur.	9	14 38 34.3	48.23	14 25.75	0.063	21 17 26.46
Fri.	10	14 19 9.3	+48.84	14 26.86	0.030	21 21 23.01
Sat.	11	13 59 30.0	49.42	14 27.20	0.002	21 25 19.56
Sun.	12	13 39 36.9	49.99	14 26.75	0.034	21 29 16.12
Mon.	13	13 19 30.5	+50.54	14 25.55	0.066	21 33 12.67
Tues.	14	12 59 11.1	51.07	14 23.58	0.098	21 37 9.23
Wed.	15	12 38 39.2	51.58	14 20.86	0.129	21 41 5.78
Thur.	16	12 17 55.3	+52.07	14 17.40	0.160	21 45 2.34
Fri.	17	11 56 59.7	52.55	14 13.21	0.190	21 48 58.89
Sat.	18	11 35 52.8	53.01	14 8.30	0.219	21 52 55.45
Sun.	19	11 14 35.2	+53.45	14 2.69	0.248	21 56 52.00
Mon.	20	10 53 7.1	53.88	13 56.39	0.276	22 0 48.56
Tues.	21	10 31 29.0	54.29	13 49.42	0.304	22 4 45.11
Wed.	22	10 9 41.3	+54.68	13 41.78	0.331	22 8 41.66
Thur.	23	9 47 44.3	55.06	13 33.52	0.357	22 12 38.22
Fri.	24	9 25 38.5	55.42	13 24.63	0.382	22 16 34.77
Sat.	25	9 3 24.2	+55.76	13 15.15	0.407	22 20 31.32
Sun.	26	8 41 1.7	56.09	13 5.08	0.431	22 24 27.88
Mon.	27	8 18 31.5	56.41	12 54.47	0.454	22 28 24.43
Tues.	28	7 55 54.0	56.71	12 43.31	0.475	22 32 20.98
Wed.	29	S 7 33 9.5	+56.99	12 31.64	0.496	22 36 17.54

FEBRUARY, 1899

Greenwich Mean Time

IV

Day of the Month	The Moon's Semi-Diameter Noon	Semi-Diameter Midnight	Horizontal Parallax Noon	Diff. for 1 Hour	Horizontal Parallax Midnight	Diff. for 1 Hour	Upper Transit Meridian of Greenwich	Diff. for 1 Hour
	′ ″	′ ″	′ ″	″	′ ″	″	h m	m
1	15 16.3	15 21.5	55 56.0	+1.55	56 15.4	+1.68	16 35.1	1.96
2	15 27.3	15 33.4	56 36.4	1.80	56 58.8	1.92	17 24.0	2.12
3	15 39.8	15 46.5	57 22.5	2.02	57 47.2	2.09	18 17.1	2.30
4	15 53.5	16 0.5	58 12.7	+2.13	58 38.5	+2.15	19 14.4	2.47
5	16 7.5	16 14.4	59 4.2	2.12	59 29.4	2.04	20 15.3	2.58
6	16 20.8	16 26.8	59 53.2	1.90	60 15.1	1.73	21 17.8	2.61
7	16 32.1	16 36.5	60 34.6	+1.48	60 50.7	+1.18	22 19.7	2.54
8	16 39.9	16 42.1	61 3.1	0.85	61 11.2	+0.48	23 19.3	2.42
9	16 43.0	16 42.6	61 14.5	+0.08	61 13.0	−0.33	☌	
10	16 40.8	16 37.8	61 6.6	−0.73	60 55.4	−1.11	0 15.8	2.29
11	16 33.5	16 28.2	60 39.8	1.46	60 20.3	1.76	1 9.4	2.18
12	16 22.0	16 15.1	59 57.5	2.01	59 32.1	2.20	2 0.8	2.11
13	16 7.6	15 59.8	59 4.7	−2.33	58 36.1	−2.40	2 51.0	2.08
14	15 51.9	15 44.1	58 7.0	2.42	57 38.1	2.38	3 40.8	2.08
15	15 36.3	15 29.0	57 9.8	2.31	56 42.7	2.19	4 31.0	2.10
16	15 22.0	15 15.5	56 17.2	−2.05	55 53.4	−1.89	5 21.7	2.12
17	15 9.7	15 4.4	55 31.8	1.71	55 12.4	1.52	6 12.8	2.13
18	14 59.7	14 55.8	54 55.3	1.32	54 40.7	1.12	7 3.9	2.12
19	14 52.4	14 49.7	54 28.5	−0.92	54 18.6	−0.72	7 54.3	2.08
20	14 47.7	14 46.2	54 11.1	0.53	54 5.8	0.35	8 43.4	2.01
21	14 45.4	14 45.1	54 2.6	−0.18	54 1.4	−0.03	9 30.7	1.93
22	14 45.2	14 45.8	54 2.0	+0.12	54 4.3	+0.26	10 16.0	1.85
23	14 46.9	14 48.3	54 8.2	0.38	54 13.5	0.50	10 59.6	1.79
24	14 50.1	14 52.3	54 20.1	0.60	54 27.9	0.69	11 42.0	1.75
25	14 54.7	14 57.3	54 36.7	+0.78	54 46.5	+0.85	12 23.8	1.74
26	15 0.2	15 3.3	54 57.1	0.92	55 8.6	0.99	13 5.8	1.76
27	15 6.7	15 10.3	55 20.9	1.05	55 34.0	1.12	13 48.8	1.83
28	15 14.0	15 18.0	55 47.9	1.18	56 2.4	1.25	14 33.8	1.92
29	15 22.2	15 26.6	56 17.8	+1.31	56 33.9	+1.37	15 21.5	2.06

MARCH, 1899

At Greenwich Apparent Noon

I

Day of the Week	Day of the Month	The Sun's Apparent Right Ascension	Diff. for 1 Hr.	Apparent Declination	Diff. for 1 Hr.	Semi-Diameter	Equation of Time, to be Added to Apparent Time	Diff. for 1 Hr.
		h m s	s	° ′ ″	″	′ ″	m s	s
Wed.	1	22 48 51.13	9.35	S 7 32 57.5	+56.99	16 10.46	12 31.54	0.497
Thur.	2	22 52 35.49	9.33	7 10 6.5	57.25	16 10.21	12 19.37	0.517
Fri.	3	22 56 19.37	9.31	6 47 9.4	57.50	16 9.96	12 6.73	0.536
Sat.	4	23 0 2.79	9.30	6 24 6.4	+57.74	16 9.71	11 53.64	0.554
Sun.	5	23 3 45.79	9.28	6 0 57.9	57.96	16 9.45	11 40.12	0.572
Mon.	6	23 7 28.36	9.26	5 37 44.5	58.16	16 9.19	11 26.18	0.589
Tues.	7	23 11 10.54	9.25	5 14 26.4	+58.34	16 8.93	11 11.84	0.605
Wed.	8	23 14 52.34	9.23	4 51 4.0	58.51	16 8.67	10 57.13	0.620
Thur.	9	23 18 33.78	9.21	4 27 37.9	58.66	16 8.41	10 42.06	0.635
Fri.	10	23 22 14.87	9.20	4 4 8.3	+58.79	16 8.15	10 26.64	0.649
Sat.	11	23 25 55.63	9.19	3 40 35.7	58.91	16 7.88	10 10.89	0.662
Sun.	12	23 29 36.09	9.17	3 17 0.5	59.01	16 7.62	9 54.84	0.675
Mon.	13	23 33 16.24	9.16	2 53 23.2	+59.09	16 7.35	9 38.48	0.687
Tues.	14	23 36 56.12	9.15	2 29 43.9	59.16	16 7.09	9 21.85	0.698
Wed.	15	23 40 35.73	9.14	2 6 3.3	59.21	16 6.83	9 4.96	0.709
Thur.	16	23 44 15.10	9.13	1 42 21.7	+59.25	16 6.57	8 47.82	0.719
Fri.	17	23 47 54.24	9.12	1 18 39.4	59.27	16 6.30	8 30.46	0.728
Sat.	18	23 51 33.18	9.11	0 54 56.8	59.27	16 6.04	8 12.89	0.736
Sun.	19	23 55 11.92	9.11	0 31 14.3	+59.26	16 5.77	7 55.13	0.743
Mon.	20	23 58 50.50	9.10	S 0 7 32.3	59.24	16 5.50	7 37.20	0.750
Tues.	21	0 2 28.93	9.09	N 0 16 9.0	59.20	16 5.23	7 19.13	0.756
Wed.	22	0 6 7.23	9.09	0 39 49.0	+59.14	16 4.96	7 0.93	0.761
Thur.	23	0 9 45.43	9.09	1 3 27.6	59.07	16 4.69	6 42.62	0.764
Fri.	24	0 13 23.54	9.08	1 27 4.4	58.99	16 4.42	6 24.24	0.767
Sat.	25	0 17 1.60	9.08	1 50 39.0	+58.89	16 4.15	6 5.79	0.769
Sun.	26	0 20 39.62	9.08	2 14 11.2	58.78	16 3.87	5 47.31	0.770
Mon.	27	0 24 17.64	9.08	2 37 40.5	58.66	16 3.59	5 28.82	0.770
Tues.	28	0 27 55.66	9.08	3 1 6.7	+58.52	16 3.31	5 10.35	0.769
Wed.	29	0 31 33.73	9.08	3 24 29.4	58.37	16 3.03	4 51.91	0.767
Thur.	30	0 35 11.85	9.09	3 47 48.4	58.21	16 2.75	4 33.53	0.764
Fri.	31	0 38 50.06	9.09	4 11 3.2	58.03	16 2.47	4 15.23	0.760
Sat.	32	0 42 28.37	9.09	N 4 34 13.5	+57.83	16 2.18	3 57.04	0.755

MARCH, 1899

AT GREENWICH MEAN NOON

II

Day of the Week	Day of the Month	The Sun's Apparent Declination	The Sun's Diff. for 1 Hour	Equation of Time, to be Subtracted From Mean Time	Diff. for 1 Hour	Sidereal Time, or Right Ascension of Mean Sun
		° ′ ″	″	m s	s	h m s
Wed.	1	S 7 33 9.5	+56.99	12 31.64	0.496	22 36 17.54
Thur.	2	7 10 18.4	57.26	12 19.48	0.516	22 40 14.09
Fri.	3	6 47 21.0	57.51	12 6.84	0.536	22 44 10.64
Sat.	4	6 24 17.9	+57.75	11 53.75	0.555	22 48 7.20
Sun.	5	6 1 9 3	57.97	11 40.23	0.572	22 52 3.75
Mon.	6	5 37 55.6	58.17	11 26.29	0.589	22 56 0.30
Tues.	7	5 14 37.3	+58.35	11 11.96	0.605	22 59 56.86
Wed.	8	4 51 14.8	58.52	10 57.25	0.620	23 3 53.41
Thur.	9	4 27 48.4	58.67	10 42.17	0.635	23 7 49.96
Fri.	10	4 4 18.6	+58.80	10 26.75	0.649	23 11 46.52
Sat.	11	3 40 45.8	58.92	10 11.01	0.663	23 15 43.07
Sun.	12	3 17 10.3	59.02	9 54.95	0.675	23 19 39.62
Mon.	13	2 53 32.7	+59.10	9 38.60	0.687	23 23 36.17
Tues.	14	2 29 53.2	59.17	9 21.96	0.698	23 27 32.73
Wed.	15	2 6 12.3	59.22	9 5.07	0.709	23 31 29.28
Thur.	16	1 42 30.4	+59.26	8 47.93	0.719	23 35 25.83
Fri.	17	1 18 47.8	59.28	8 30.56	0.728	23 39 22.38
Sat.	18	0 55 4.9	59.28	8 12.99	0.736	23 43 18.94
Sun.	19	0 31 22.2	+59.27	7 55.23	0.744	23 47 15.49
Mon.	20	S 0 7 39.8	59.25	7 37.30	0.750	23 51 12.04
Tues.	21	N 0 16 1.7	59.21	7 19.22	0.756	23 55 8.60
Wed.	22	0 39 42.1	+59.15	7 1.02	0.761	23 59 5.15
Thur.	23	1 3 21.0	59.08	6 42.71	0.765	0 3 1.70
Fri.	24	1 26 58.1	59.00	6 24.32	0.767	0 6 58.26
Sat.	25	1 50 33.0	+58.90	6 5.87	0.769	0 10 54.81
Sun.	26	2 14 5.5	58.79	5 47.39	0.770	0 14 51.36
Mon.	27	2 37 35.1	58.67	5 28.90	0.770	0 18 47.91
Tues.	28	3 1 1.6	+58.53	5 10.41	0.769	0 22 44.47
Wed.	29	3 24 24.7	58.38	4 51.97	0.767	0 26 41.02
Thur.	30	3 47 44.0	58.22	4 33.59	0.764	0 30 37.57
Fri.	31	4 10 59.0	58.04	4 15.29	0.760	0 34 34.12
Sat.	32	N 4 34 9.7	+57.84	3 57.09	0.756	0 38 30.68

MARCH, 1899

Greenwich Mean Time

IV.

Day of the Month	The Moon's Semi-Diameter Noon	Semi-Diameter Midnight	Horizontal Parallax Noon	Diff. for 1 Hour	Horizontal Parallax Midnight	Diff. for 1 Hour	Upper Transit Meridian of Greenwich	Diff. for 1 Hour
	′ ″	′ ″	′ ″	″	′ ″	″	h m	m
1	15 22.2	15 26.6	56 17.8	+1.31	56 33.9	+1.37	15 21.5	2.06
2	15 31.2	15 36.0	56 50.8	1.43	57 8.4	1.49	16 12.6	2.21
3	15 40.9	15 46.0	57 26.6	1.54	57 45.4	1.58	17 7.4	2.35
4	15 51.3	15 56.5	58 4.6	+1.60	58 24.0	+1.62	18 5.2	2.46
5	16 1.8	16 7.0	58 43.4	1.60	59 2.4	1.56	19 4.9	2.50
6	16 12.0	16 16.7	59 20.8	1.48	59 38.1	1.37	20 4.8	2.48
7	16 21.0	16 24.7	59 53.7	+1.22	60 7.4	+1.03	21 3.4	2.39
8	16 27.8	16 30.0	60 18.6	0.80	60 26.8	+0.54	21 59.6	2.29
9	16 31.3	16 31.6	60 31.7	+0.25	60 32.9	−0.06	22 53.6	2.20
10	16 30.9	16 29.0	60 30.3	−0.38	60 23.7	+0.70	23 45.7	2.14
11	16 26.3	16 22.5	60 13.3	1.02	59 59.2	1.31	♂	
12	16 17.7	16 12.2	59 41.8	1.57	59 21.5	1.79	0 36.8	2.12
13	16 6.0	15 59.4	58 58.8	−1.96	58 34.3	−2.09	1 27.6	2.12
14	15 52.4	15 45.2	58 8.6	2.17	57 42.3	2.19	2 18.9	2.15
15	15 38.0	15 31.0	57 15.9	2.18	56 50.1	2.11	3 10.8	2.18
16	15 24.2	15 17.8	56 25.2	−2.02	56 1.6	−1.89	4 3.2	2.19
17	15 11.8	15 6.5	55 39.8	1.73	55 20.0	1.55	4 55.6	2.17
18	15 1.7	14 57.5	55 2.4	1.36	54 47.2	1.16	5 47.2	2.12
19	14 54.1	14 51.3	54 34.5	−0.95	54 24.4	−0.74	6 37.4	2.05
20	14 49.2	14 47.9	54 16.8	0.52	54 11.8	−0.31	7 25.5	1.96
21	14 47.2	14 47.1	54 9.3	−0.11	54 9.1	+0.08	8 11.6	1.88
22	14 47.7	14 48.9	54 11.3	+0.27	54 15.6	+0.44	8 55.7	1.81
23	14 50.6	14 52.8	54 21.9	0.60	54 29.9	0.74	9 38.5	1.76
24	14 55.5	14 58.4	54 39.6	0.86	54 50.6	0.97	10 20.6	1.75
25	15 1.8	15 5.4	55 2.9	+1.06	55 16.1	+1.13	11 2.8	1.77
26	15 9.2	15 13.1	55 30.0	1.18	55 44.5	1.22	11 45.9	1.83
27	15 17.2	15 21.3	55 59.4	1.25	56 14.5	1.26	12 30.9	1.92
28	15 25.4	15 29.5	56 29.6	+1.25	56 44.7	+1.25	13 18.4	2.05
29	15 33.6	15 37.5	56 59.6	1.23	57 14.2	1.20	14 9.2	2.19
30	15 41.4	15 45.3	57 28.5	1.18	57 42.5	1.15	15 3.4	2.32
31	15 48.9	15 52.5	57 56.0	1.11	58 9.1	1.08	16 0.5	2.42
32	15 56.0	15 59.3	58 21.8	+1.03	58 34.0	+0.99	16 59.2	2.46

MARCH, 1899

GREENWICH MEAN TIME

The Moon's Right Ascension and Declination

(SATURDAY, 18)

Hour	Right Ascension	Diff. for 1 Minute	Declination	Diff. for 1 Minute
	h m s	s	° ′ ″	″
0	5 18 38.98	2.2291	N 24 20 42.1	0.429
1	5 20 52.66	2.2269	24 20 12.7	0.550
2	5 23 6.21	2.2247	24 19 36.1	0.671
3	5 25 19.62	2.2224	24 18 52.2	0.792
4	5 27 32.90	2.2201	24 18 1.0	0.912
5	5 29 46.03	2.2177	24 17 2.7	1.032
6	5 31 59.03	2.2154	24 15 57.1	1.152
7	5 34 11.88	2.2130	24 14 44.4	1.272
8	5 36 24.59	2.2105	24 13 24.5	1.390
9	5 38 37.14	2.2080	24 11 57.6	1.508
10	5 40 49.55	2.2055	24 10 23.5	1.627
11	5 43 1.80	2.2029	24 8 42.4	1.744
12	5 45 13.90	2.2003	24 6 54.2	1.862
13	5 47 25.84	2.1977	24 4 59.0	1.978
14	5 49 37.62	2.1950	24 2 56.8	2.094
15	5 51 49.24	2.1922	24 0 47.7	2.210
16	5 54 0.69	2.1894	23 58 31.6	2.326
17	5 56 11.97	2.1867	23 56 8.6	2.440
18	5 58 23.09	2.1839	23 53 38.8	2.553
19	6 0 34.04	2.1811	23 51 2.2	2.667
20	6 2 44.82	2.1782	23 48 18.7	2.782
21	6 4 55.42	2.1752	23 45 28.4	2.894
22	6 7 5.84	2.1722	23 42 31.4	3.006
23	6 9 16.09	2.1693	23 39 27.7	3.117
24	6 11 26.16	2.1663	N 23 36 17.3	3.228

MARCH, 1899

Greenwich Mean Time

The Moon's Right Ascension and Declination

(Saturday, 25)

Hour	Right Ascension	Diff. for 1 Minute	Declination	Diff. for 1 Minute
	h m s	s	° ′ ″	″
0	10 54 46.93	1.8715	N 1 50 52.8	12.628
1	10 56 39.25	1.8724	1 38 14.6	12.644
2	10 58 31.62	1.8733	1 25 35.5	12.659
3	11 0 24.05	1.8743	1 12 55.5	12.673
4	11 2 16.54	1.8754	1 0 14.7	12.686
5	11 4 9.10	1.8766	0 47 33.2	12.697
6	11 6 1.73	1.8777	0 34 51.0	12.709
7	11 7 54.43	1.8790	0 22 8.1	12.720
8	11 9 47.21	1.8803	N 0 9 24.6	12.730
9	11 11 40.07	1.8817	S 0 3 19.5	12.739
10	11 13 33.01	1.8830	0 16 4.1	12.747
11	11 15 26.03	1.8845	0 28 49.1	12.753
12	11 17 19.15	1.8861	0 41 34.5	12.760
13	11 19 12.36	1.8877	0 54 20.3	12.766
14	11 21 5.67	1.8892	1 7 6.4	12.771
15	11 22 59.07	1.8909	1 19 52.8	12.775
16	11 24 52.58	1.8927	1 32 39.4	12.778
17	11 26 46.19	1.8944	1 45 26.2	12.781
18	11 28 39.91	1.8963	1 58 13.1	12.782
19	11 30 33.75	1.8983	2 11 0 0	12.782
20	11 32 27.71	1.9002	2 23 46.9	12.782
21	11 34 21.78	1.9022	2 36 33.8	12.780
22	11 36 15.98	1.9043	2 49 20.5	12.777
23	11 38 10.30	1.9065	3 2 7.1	12.774

APRIL, 1899

At Greenwich Apparent Noon

I.

Day of the Week	Day of the Month	The Sun's Apparent Right Ascension	Diff. for 1 Hr.	Apparent Declination	Diff. for 1 Hr.	Semi-Diameter	Equation of Time, to be Added to / Subtracted From Apparent Time	Diff. for 1 Hr.
		h m s	s	° ′ ″	″	′ ″	m s	s
Sat.	1	0 42 28.37	9.09	N 4 34 13.5	+57.83	16 2.18	3 57.04	0.755
Sun.	2	0 46 6.81	9.10	4 57 19.0	57.62	16 1.90	3 38.98	0.749
Mon.	3	0 49 45.39	9.11	5 20 19.3	57.40	16 1.62	3 21.06	0.743
Tues.	4	0 53 24.14	9.11	5 43 14.2	+57.16	16 1.34	3 3.30	0.736
Wed.	5	0 57 3.07	9.12	6 6 3.1	56.91	16 1.06	2 45.73	0.728
Thur.	6	1 0 42.20	9.13	6 28 45.9	56.64	16 0.78	2 28.36	0.719
Fri.	7	1 4 21.56	9.14	6 51 22.0	+56.36	16 0.50	2 11.20	0.710
Sat.	8	1 8 1.14	9.15	7 13 51.2	56.06	16 0.22	1 54.28	0.700
Sun.	9	1 11 40.97	9.16	7 36 13.0	55.75	15 59.94	1 37.60	0.689
Mon.	10	1 15 21.06	9.17	7 58 27.2	+55.42	15 59.67	1 21.18	0.678
Tues.	11	1 19 1.43	9.18	8 20 33.3	55.08	15 59.40	1 5.05	0.667
Wed.	12	1 22 42.09	9.20	8 42 31.0	54.72	15 59.13	0 49.19	0.655
Thur.	13	1 26 23.04	9.21	9 4 19.9	+54.35	15 58.86	0 33.64	0.642
Fri.	14	1 30 4.31	9.22	9 25 59.8	53.96	15 58.60	0 18.39	0.629
Sat.	15	1 33 45.91	9.24	9 47 30.2	53.56	15 58.34	0 3.47	0.615
Sun.	16	1 37 27.84	9.25	10 8 50.8	+53.15	15 58.08	0 11.10	0.600
Mon.	17	1 41 10.13	9.26	10 30 1.2	52.72	15 57.82	0 25.33	0.585
Tues.	18	1 44 52.78	9.28	10 51 1.2	52.28	15 57.56	0 39.20	0.570
Wed.	19	1 48 35.81	9.30	11 11 50.4	+51.82	15 57.30	0 52.69	0.554
Thur.	20	1 52 19.23	9.31	11 32 28.5	51.35	15 57.05	1 5.78	0.537
Fri.	21	1 56 3.07	9.33	11 52 55.2	50.86	15 56.79	1 18.46	0.520
Sat.	22	1 59 47.33	9.35	12 13 10.1	+50.37	15 56.54	1 30.72	0.502
Sun.	23	2 3 32.03	9.37	12 33 13.1	49.86	15 56.29	1 42.55	0.483
Mon.	24	2 7 17.18	9.39	12 53 3.6	49.34	15 56.04	1 53.92	0.464
Tues.	25	2 11 2.81	9.41	13 12 41.6	+48.81	15 55.79	2 4.82	0.444
Wed.	26	2 14 48.92	9.43	13 32 6.5	48.27	15 55.54	2 15.23	0.424
Thur.	27	2 18 35.53	9.45	13 51 18.2	47.71	15 55.29	2 25.14	0.403
Fri.	28	2 22 22.66	9.47	14 10 16.4	+47.14	15 55.04	2 34.55	0.381
Sat.	29	2 26 10.31	9.49	14 29 0.6	46.55	15 54.79	2 43.43	0.359
Sun.	30	2 29 58.50	9.51	14 47 30.6	45.95	15 54.55	2 51.77	0.336
Mon.	31	2 33 47.24	9.54	N 15 5 46.1	+45.34	15 54.30	2 59.56	0.313

APRIL, 1899

At Greenwich Mean Noon

II.

Day of the Week	Day of the Month	The Sun's Apparent Declination	The Sun's Diff. for 1 Hour	Equation of Time, to be Subtracted From / Added to Mean Time	Diff. for 1 Hour	Sidereal Time, or Right Ascension of Mean Sun
		° ′ ″	″	m s	s	h m s
Sat.	1	N 4 34 9.7	+57.84	3 57.09	0.756	0 38 30.68
Sun.	2	4 57 15.5	57.63	3 39.02	0.750	0 42 27.25
Mon.	3	5 20 16.1	57.41	3 21.10	0.743	0 46 23.78
Tues.	4	5 43 11.3	+57.17	3 3.34	0.736	0 50 20.34
Wed.	5	6 6 0.5	56.92	2 45.76	0.728	0 54 16.89
Thur.	6	6 28 43.5	56.65	2 28.39	0.719	0 58 13.44
Fri.	7	6 51 20.0	+56.37	2 11.23	0.710	1 2 10.00
Sat.	8	7 13 49.4	56.07	1 54.30	0.700	1 6 6.55
Sun.	9	7 36 11.5	55.76	1 37.62	0.690	1 10 3.10
Mon.	10	7 58 25.9	+55.43	1 21.20	0.679	1 13 59.66
Tues.	11	8 20 32.3	55.09	1 5.06	0.667	1 17 56.21
Wed.	12	8 42 30.3	54.73	0 49.20	0.655	1 21 52.76
Thur.	13	9 4 19.5	+54.36	0 33.64	0.642	1 25 49.32
Fri.	14	9 25 59.6	53.97	0 18.40	0.629	1 29 45.87
Sat.	15	9 47 30.2	53.57	0 3.48	0.615	1 33 42.42
Sun.	16	10 8 51.0	+53.16	0 11.11	0.600	1 37 38.98
Mon.	17	10 30 1.6	52.73	0 25.34	0.585	1 41 35.53
Tues.	18	10 51 1.8	52.29	0 39.21	0.570	1 45 32.08
Wed.	19	11 11 51.2	+51.83	0 52.69	0.554	1 49 28.64
Thur.	20	11 32 29.5	51.36	1 5.79	0.537	1 53 25.19
Fri.	21	11 52 56.3	50.87	1 18.48	0.520	1 57 21.75
Sat.	22	12 13 11.4	+50.38	1 30.74	0.502	2 1 18.30
Sun.	23	12 33 14.5	49.87	1 42.56	0.483	2 5 14.86
Mon.	24	12 53 5.2	49.35	1 53.93	0.464	2 9 11.41
Tues.	25	13 12 43.3	+48.82	2 4.83	0.444	2 13 7.96
Wed.	26	13 32 8.4	48.27	2 15.24	0.424	2 17 4.52
Thur.	27	13 51 20.2	47.71	2 25.16	0.403	2 21 1.07
Fri.	28	14 10 18.4	+47.14	2 34.57	0.381	2 24 57.63
Sat.	29	14 29 2.7	46.55	2 43.44	0.359	2 28 54.18
Sun.	30	14 47 32.9	45.95	2 51.79	0.336	2 32 50.74
Mon.	31	N 15 5 48.4	+45.34	2 59.58	0.313	2 36 47.29

APRIL, 1899

Greenwich Mean Time

IV

Day of the Month	The Moon's							
	Semi-Diameter		Horizontal Parallax				Upper Transit	
	Noon	Midnight	Noon	Diff. for 1 Hour	Midnight	Diff. for 1 Hour	Meridian of Greenwich	Diff. for 1 Hour
	′ ″	′ ″	′ ″	″	′ ″	″	h m	m
1	15 56.0	15 59.3	58 21.8	+1.03	58 34.0	+0.99	16 59.2	2.46
2	16 2.4	16 5.4	58 45.6	0.94	58 56.5	0.88	17 58.1	2.43
3	16 8.1	16 10.7	59 6.6	0.80	59 15.8	0.72	18 55.5	2.35
4	16 12.8	16 14.7	59 23.8	+0.62	59 30.6	+0.49	19 50.7	2.25
5	16 16.1	16 17.0	59 35.7	0.35	59 39.0	+0.19	20 43.6	2.16
6	16 17.3	16 17.1	59 40.3	+0.02	59 39.4	−0.18	21 34.8	2.11
7	16 16.2	16 14.6	59 36.1	−0.38	59 30.2	−0.60	22 25.0	2.08
8	16 12.3	16 9.3	59 21.8	0.81	59 10.8	1.02	23 15.1	2.10
9	16 5.6	16 1.4	58 57.3	1.21	58 41.7	1.39	☌	
10	15 56.5	15 51.3	58 23.9	−1.54	58 4.6	−1.66	0 5.9	2.14
11	15 45.7	15 39.8	57 44.1	1.75	57 22.6	1.81	0 57.7	2.18
12	15 33.9	15 27.9	57 0.7	1.83	56 38.8	1.80	1 50.6	2.22
13	15 22.1	15 16.4	56 17.3	−1.75	55 56.6	−1.67	2 44.0	2.22
14	15 11.1	15 6.2	55 37.1	1.56	55 19.2	1.42	3 37.0	2.19
15	15 1.8	14 58.0	55 3.0	1.26	54 48.9	1.08	4 28.7	2.11
16	14 54.7	14 52.2	54 37.0	−0.89	54 27.5	−0.68	5 18.2	2.01
17	14 50.3	14 49.1	54 20.6	0.47	54 16.2	−0.25	6 5.3	1.91
18	14 48.6	14 48.8	54 14.4	−0.04	54 15.3	+0.18	6 50.2	1.83
19	14 49.8	14 51.3	54 18.7	+0.38	54 24.5	+0.58	7 33.3	1.77
20	14 53.6	14 56.4	54 32.7	0.78	54 43.2	0.95	8 15.4	1.74
21	14 59.8	15 3.7	54 55.6	1.11	55 9.8	1.25	8 57.3	1.75
22	15 8.0	15 12.6	55 25.6	+1.37	55 42.6	+1.46	9 40.0	1.81
23	15 17.5	15 22.6	56 0.6	1.53	56 19.2	1.56	10 24.3	1.90
24	15 27.7	15 32.9	56 38.2	1.58	56 57.1	1.56	11 11.3	2.03
25	15 38.0	15 42.8	57 15.7	+1.52	57 33.5	+1.45	12 1.7	2.18
26	15 47.4	15 51.7	57 50.5	1.36	58 6.3	1.25	12 55.9	2.33
27	15 55.8	15 59.2	58 20.7	1.13	58 33.6	1.00	13 53.4	2.45
28	16 2.2	16 4.8	58 44.8	+0.87	58 54.4	+0.73	14 53.0	2.50
29	16 6.9	16 8.7	59 2.2	0.59	59 8.5	0.45	15 52.8	2.47
30	16 9.9	16 10.8	59 13.1	0.32	59 16.2	+0.20	16 51.1	2.38
31	16 11.2	16 11.3	59 17.9	+0.08	59 18.2	−0.03	17 46.8	2.26

APRIL, 1899
Greenwich Mean Time
The Moon's Right Ascension and Declination

X

(Wednesday, 19)

Hour	Right Ascension	Diff. for 1 Minute	Declination	Diff. for 1 Minute
	h m s	s	° ′ ″	″
0	9 9 46.08	1.8975	N 12 37 18.7	10.503
1	9 11 39.87	1.8955	12 26 46.9	10.557
2	9 13 33.54	1.8936	12 16 11.9	10.608
3	9 15 27.10	1.8917	12 5 33.9	10.660
4	9 17 20.54	1.8898	11 54 52.7	10.712
5	9 19 13.87	1.8879	11 44 8.5	10.762
6	9 21 7.09	1.8861	11 33 21.3	10.811
7	9 23 0.20	1.8844	11 22 31.2	10.860
8	9 24 53.22	1.8828	11 11 38.1	10.909
9	9 26 46.13	1.8811	11 0 42.1	10.958
10	9 28 38.95	1.8795	10 49 43.2	11.004
11	9 30 31.67	1.8780	10 38 41.6	11.051
12	9 32 24.31	1.8766	10 27 37.1	11.098
13	9 34 16.86	1.8752	10 16 29.9	11.143
14	9 36 9.33	1.8738	10 5 20.0	11.187
15	9 38 1.72	1.8725	9 54 7.5	11.231
16	9 39 54.03	1.8713	9 42 52.3	11.275
17	9 41 46.27	1.8701	9 31 34.5	11.318
18	9 43 38.44	1.8689	9 20 14.1	11.360
19	9 45 30.54	1.8678	9 8 51.3	11.402
20	9 47 22.58	1.8668	8 57 25.9	11.443
21	9 49 14.56	1.8658	8 45 58.1	11.483
22	9 51 6.48	1.8648	8 34 27.9	11.523
23	9 52 58.34	1.8639	N 8 22 55.4	11.562

MAY, 1899

At Greenwich Apparent Noon

Day of the Week	Day of the Month	The Sun's Apparent Right Ascension	Diff. for 1 Hr.	The Sun's Apparent Declination	Diff. for 1 Hr.	The Sun's Semi-Diameter	Equation of Time, to be Subtracted From Apparent Time	Diff. for 1 Hr.
		h m s	s	° ′ ″	″	′ ″	m s	s
Mon.	1	2 33 47.24	9.54	N 15 5 46.1	+45.34	15 54.30	2 59.56	0.313
Tues.	2	2 37 36.53	9.56	15 23 46.8	44.71	15 54.06	3 6.80	0.290
Wed.	3	2 41 26.40	9.59	15 41 32.2	44.07	15 53.82	3 13.48	0.266
Thur.	4	2 45 16.83	9.61	15 59 2.2	+43.42	15 53.58	3 19.58	0.242
Fri.	5	2 49 7.84	9.63	16 16 16.4	42.76	15 53.35	3 25.11	0.218
Sat.	6	2 52 59.43	9.66	16 33 14.4	42.08	15 53.12	3 30.07	0.194
Sun.	7	2 56 51.60	9.68	16 49 56.0	+41.38	15 52.89	3 34.44	0.170
Mon.	8	3 0 44.35	9.71	17 6 20.8	40.67	15 52.67	3 38.24	0.146
Tues.	9	3 4 37.68	9.73	17 22 28.5	39.96	15 52.45	3 41.45	0.122
Wed.	10	3 8 31.59	9.75	17 38 18.8	+39.23	15 52.23	3 44.09	0.098
Thur.	11	3 12 26.07	9.78	17 53 51.3	38.48	15 52.02	3 46.16	0.074
Fri.	12	3 16 21.13	9.80	18 9 5.9	37.72	15 51.82	3 47.66	0.050
Sat.	13	3 20 16.75	9.82	18 24 2.1	+36.95	15 51.62	3 48.59	0.027
Sun.	14	3 24 12.93	9.85	18 38 39.7	36.17	15 51.42	3 48.96	0.004
Mon.	15	3 28 9.67	9.87	18 52 58.4	35.38	15 51.22	3 48.78	0.019
Tues.	16	3 32 6.96	9.89	19 6 58.0	+34.58	15 51.03	3 48.04	0.042
Wed.	17	3 36 4.80	9.92	19 20 38.2	33.76	15 50.84	3 46.76	0.065
Thur.	18	3 40 3.19	9.94	19 33 58.6	32.93	15 50.66	3 44.94	0.087
Fri.	19	3 44 2.10	9.96	19 46 59.1	+32.10	15 50.48	3 42.58	0.109
Sat.	20	3 48 1.56	9.98	19 59 39.4	31.25	15 50.30	3 39.69	0.131
Sun.	21	3 52 1.54	10.01	20 11 59.3	30.39	15 50.13	3 36.28	0.153
Mon.	22	3 56 2.05	10.03	20 23 58.5	+29.52	15 49.96	3 32.34	0.175
Tues.	23	4 0 3.07	10.05	20 35 36.7	28.65	15 49.79	3 27.88	0.196
Wed.	24	4 4 4.61	10.07	20 46 53.9	27.77	15 49.62	3 22.91	0.218
Thur.	25	4 8 6.66	10.09	20 57 49.6	+26.87	15 49.45	3 17.44	0.239
Fri.	26	4 12 9.21	10.11	21 8 23.8	25.96	15 49.29	3 11.46	0.260
Sat.	27	4 16 12.25	10.13	21 18 36.1	25.05	15 49.13	3 5.00	0.280
Sun.	28	4 20 15.78	10.15	21 28 26.4	+24.13	15 48.97	2 58.04	0.300
Mon.	29	4 24 19.78	10.17	21 37 54.5	23.20	15 48.81	2 50.62	0.319
Tues.	30	4 28 24.25	10.19	21 47 0.1	22.26	15 48.66	2 42.73	0.338
Wed.	31	4 32 29.17	10.21	21 55 43.1	21.31	15 48.51	2 34.39	0.357
Thur.	32	4 36 34.53	10.23	N 22 4 3.2	+20.36	15 48.37	2 25.61	0.374

MAY, 1899

II

At Greenwich Mean Noon

Day of the Week	Day of the Month	The Sun's Apparent Declination	The Sun's Diff. for 1 Hour	Equation of Time, to be Added to Mean Time	Diff. for 1 Hour	Sidereal Time, or Right Ascension of Mean Sun
		° ′ ″	″	m s	s	h m s
Mon.	1	N 15 5 48.4	+45.34	2 59.58	0.313	2 36 47.29
Tues.	2	15 23 49.1	44.71	3 6.82	0.290	2 40 43.85
Wed.	3	15 41 34.6	44.07	3 13.49	0.266	2 44 40.40
Thur.	4	15 59 4.7	+43.42	3 19.60	0.242	2 48 36.96
Fri.	5	16 16 18.9	42.76	3 25.13	0.218	2 52 33.52
Sat.	6	16 33 16.9	42.08	3 30.08	0.194	2 56 30.07
Sun.	7	16 49 58.5	+41.38	3 34.46	0.170	3 0 26.63
Mon.	8	17 6 23.3	40.67	3 38.25	0.146	3 4 23.18
Tues.	9	17 22 31.0	39.96	3 41.46	0.122	3 8 19.74
Wed.	10	17 38 21.2	+39.23	3 44.10	0.098	3 12 16.29
Thur.	11	17 53 53.8	38.48	3 46.17	0.074	3 16 12.85
Fri.	12	18 9 8.3	37.72	3 47.66	0.050	3 20 9.40
Sat.	13	18 24 4.5	+36.95	3 48.59	0.027	3 24 5.96
Sun.	14	18 38 42.1	36.17	3 48.96	0.004	3 28 2.52
Mon.	15	18 53 0.7	35.38	3 48.77	0.019	3 31 59.07
Tues.	16	19 7 0.2	+34.58	3 48.04	0.042	3 35 55.63
Wed.	17	19 20 40.3	33.76	3 46.76	0.065	3 39 52.18
Thur.	18	19 34 0.7	32.93	3 44.93	0.087	3 43 48.74
Fri.	19	19 47 1.1	+32.10	3 42.58	0.109	3 47 45.30
Sat.	20	19 59 41.4	31.25	3 39.69	0.131	3 51 41.86
Sun.	21	20 12 1.2	30.39	3 36.27	0.153	3 55 38.41
Mon.	22	20 24 0.3	+29.52	3 32.33	0.175	3 59 34.97
Tues.	23	20 35 38.4	28.65	3 27.87	0.196	4 3 31.53
Wed.	24	20 46 55.5	27.77	3 22.90	0.218	4 7 28.08
Thur.	25	20 57 51.2	+26.87	3 17.42	0.239	4 11 24.64
Fri.	26	21 8 25.2	25.96	3 11.45	0.260	4 15 21.20
Sat.	27	21 18 37.5	25.05	3 4.98	0.280	4 19 17.75
Sun.	28	21 28 27.7	+24.13	2 58.03	0.300	4 23 14.31
Mon.	29	21 37 55.6	23.20	2 50.60	0.319	4 27 10.87
Tues.	30	21 47 1.2	22.26	2 42.71	0.338	4 31 7.42
Wed.	31	21 55 44.0	21.31	2 34.37	0.357	4 35 3.98
Thur.	32	N 22 4 4.1	+20.36	2 25.59	0.375	4 39 0.54

MAY, 1899

Greenwich Mean Time

IV

Day of the Month	The Moon's Semi-Diameter Noon	Semi-Diameter Midnight	Horizontal Parallax Noon	Diff. for 1 Hour	Horizontal Parallax Midnight	Diff. for 1 Hour	Upper Transit Meridian of Greenwich	Diff. for 1 Hour
	′ ″	′ ″	′ ″	″	′ ″	″	h m	m
1	16 11.2	16 11.3	59 17.9	+0.08	59 18.2	−0.03	17 46.8	2.26
2	16 11.1	16 10.5	59 17.3	−0.13	59 15.1	0.23	18 39.6	2.15
3	16 9.6	16 8.3	59 11.8	0.33	59 7.3	0.42	19 30.1	2.07
4	16 6.8	16 4.9	59 1.6	−0.52	58 54.8	−0.62	20 19.3	2.03
5	16 2.8	16 0.2	58 46.8	0.72	58 37.5	0.82	21 8.0	2.04
6	15 57.4	15 54.2	58 27.1	0.92	58 15.4	1.02	21 57.2	2.07
7	15 50.7	15 46.9	58 2.6	−1.12	57 48.6	−1.21	22 47.7	2.13
8	15 42.8	15 38.5	57 33.6	1.28	57 17.7	1.35	23 39.6	2.19
9	15 34.0	15 29.3	57 1.1	1.40	56 44.0	1.43	☌	
10	15 24.6	15 19.9	56 26.7	−1.45	56 9.3	−1.44	0 32.7	2.23
11	15 15.2	15 10.7	55 52.1	1.40	55 35.6	1.34	1 26.1	2.22
12	15 6.4	15 2.4	55 19.9	1.26	55 5.2	1.16	2 18.8	2.16
13	14 58.8	14 55.7	54 52.0	−1.03	54 40.4	−0.89	3 9.7	2.07
14	14 53.0	14 50.9	54 30.6	0.73	54 22.8	0.55	3 58.2	1.97
15	14 49.4	14 48.5	54 17.3	−0.36	54 14.2	−0.16	4 44.1	1.86
16	14 48.3	14 48.8	54 13.5	+0.05	54 15.3	+0.26	5 27.8	1.78
17	14 50.0	14 51.9	54 19.7	0.48	54 26.7	0.69	6 10.0	1.73
18	14 54.6	14 57.8	54 36.3	0.90	54 48.3	1.10	6 51.5	1.73
19	15 1.7	15 6.3	55 2.7	+1.29	55 19.3	+1.46	7 33.2	1.76
20	15 11.3	15 16.8	55 37.8	1.61	55 58.0	1.74	8 16.2	1.83
21	15 22.7	15 28.9	56 19.7	1.84	56 42.3	1.91	9 1.6	1.96
22	15 35.2	15 41.6	57 5.6	+1.95	57 29.0	+1.94	9 50.4	2.11
23	15 47.9	15 54.0	57 52.2	1.90	58 14.6	1.81	10 43.2	2.29
24	15 59.7	16 5.0	58 35.7	1.69	58 55.1	1.53	11 40.2	2.45
25	16 9.8	16 13.8	59 12.5	+1.34	59 27.3	+1.12	12 40.5	2.56
26	16 17.1	16 19.6	59 39.3	0.88	59 48.5	0.63	13 42.2	2.57
27	16 21.2	16 22.1	59 54.6	+0.38	59 57.8	+0.14	14 43.0	2.49
28	16 22.1	16 21.5	59 58.0	−0.09	59 55.5	−0.31	15 41.1	2.35
29	16 20.1	16 18.2	59 50.6	0.50	59 43.4	0.67	16 35.9	2.22
30	16 15.7	16 12.8	59 34.4	0.82	59 23.8	0.94	17 27.6	2.10
31	16 9.6	16 6.1	59 11.9	1.03	58 58.9	1.11	18 17.1	2.03
32	16 2.3	15 58.4	58 45.2	−1.17	58 30.9	−1.20	19 5.5	2.01

JUNE, 1899

AT GREENWICH APPARENT NOON

I

Day of the Week	Day of the Month	The Sun's Apparent Right Ascension	Diff. for 1 Hr.	The Sun's Apparent Declination	Diff. for 1 Hr.	The Sun's Semi-Diameter	Equation of Time. to be Subtracted From / Added to Apparent Time	Diff. for 1 Hr.
		h m s	s	° ′ ″	″	′ ″	m s	s
Thur.	1	4 36 34.53	10.23	N 22 4 3.2	+20.36	15 48.37	2 25.61	0.374
Fri.	2	4 40 40.31	10.24	22 12 0.3	19.39	15 48.23	2 16.42	0.391
Sat.	3	4 44 46.50	10.26	22 19 34.2	18.42	15 48.09	2 6.81	0.408
Sun.	4	4 48 53.07	10.28	22 26 44.7	+17.44	15 47.96	1 56.82	0.424
Mon.	5	4 53 0.01	10.29	22 33 31.7	16.46	15 47.83	1 46.47	0.438
Tues.	6	4 57 7.29	10.31	22 39 54.9	15.47	15 47.71	1 35.78	0.452
Wed.	7	5 1 14.89	10.32	22 45 54.3	+14.47	15 47.59	1 24.76	0.465
Thur.	8	5 5 22.79	10.33	22 51 29.7	13.47	15 47.48	1 13.45	0.477
Fri.	9	5 9 30.96	10.34	22 56 41.1	12.46	15 47.38	1 1.87	0.488
Sat.	10	5 13 39.37	10.35	23 1 28.2	+11.45	15 47.28	0 50.05	0.498
Sun.	11	5 17 48.01	10.36	23 5 51.0	10.44	15 47.18	0 38.00	0.506
Mon.	12	5 21 56.84	10.37	23 9 49.4	9.42	15 47.09	0 25.76	0.513
Tues.	13	5 26 5.85	10.37	23 13 23.3	+8.40	15 47.00	0 13.35	0.520
Wed.	14	5 30 14.99	10.38	23 16 32.7	7.38	15 46.92	0 0.80	0.526
Thur.	15	5 34 24.26	10.38	23 19 17.5	6.35	15 46.85	0 11.88	0.530
Fri.	16	5 38 33.63	10.39	23 21 37.5	+5.32	15 46.78	0 24.65	0.533
Sat.	17	5 42 43.07	10.39	23 23 32.9	4.29	15 46.71	0 37.50	0.536
Sun.	18	5 46 52.56	10.39	23 25 3.6	3.26	15 46.65	0 50.40	0.538
Mon.	19	5 51 2.08	10.39	23 26 9.5	+2.23	15 46.59	1 3.33	0.539
Tues.	20	5 55 11.61	10.39	23 26 50.7	1.20	15 46.53	1 16.26	0.539
Wed.	21	5 59 21.13	10.39	23 27 7.1	+0.17	15 46.48	1 29.19	0.538
Thur.	22	6 3 30.62	10.39	23 26 58.6	−0.86	15 46.43	1 42.09	0.536
Fri.	23	6 7 40.06	10.39	23 26 25.4	1.90	15 46.39	1 54.93	0.534
Sat.	24	6 11 49.42	10.38	23 25 27.5	2.93	15 46.34	2 7.70	0.531
Sun.	25	6 15 58.69	10.38	23 24 4.8	−3.96	15 46.30	2 20.38	0.526
Mon.	26	6 20 7.86	10.37	23 22 17.4	4.99	15 46.26	2 32.96	0.521
Tues.	27	6 24 16.90	10.37	23 20 5.4	6.01	15 46.23	2 45.40	0.515
Wed.	28	6 28 25.78	10.36	23 17 28.7	−7.04	15 46.20	2 57.70	0.508
Thur.	29	6 32 34.50	10.35	23 14 27.4	8.06	15 46.18	3 9.82	0.501
Fri.	30	6 36 43.02	10.35	23 11 1.7	9.08	15 46.16	3 21.75	0.493
Sat.	31	6 40 51.34	10.34	N 23 7 11.6	−10.09	15 46.14	3 33.48	0.484

JUNE, 1899

At Greenwich Mean Noon

II.

Day of the Week	Day of the Month	The Sun's Apparent Declination	The Sun's Diff. for 1 Hour	Equation of Time, to be Added to / Subtracted From Mean Time	Diff. for 1 Hour	Sidereal Time, or Right Ascension of Mean Sun
		° ′ ″	″	m s	s	h m s
Thur.	1	N 22 4 4.1	+20.36	2 25.59	0.375	4 39 0.54
Fri.	2	22 12 1.1	19.39	2 16.40	0.392	4 42 57.10
Sat.	3	22 19 34.9	18.42	2 6.80	0.408	4 46 53.66
Sun.	4	22 26 45.3	+17.44	1 56.81	0.424	4 50 50.21
Mon.	5	22 33 32.2	16.46	1 46.45	0.438	4 54 46.77
Tues.	6	22 39 55.3	15.47	1 35.77	0.452	4 58 43.33
Wed.	7	22 45 54.7	+14.47	1 24.75	0.465	5 2 39.89
Thur.	8	22 51 30.0	13.47	1 13.45	0.477	5 6 36.44
Fri.	9	22 56 41.3	12.46	1 1.86	0.488	5 10 33.00
Sat.	10	23 1 28.4	+11.45	0 50.04	0.497	5 14 29.56
Sun.	11	23 5 51.1	10.44	0 38.00	0.506	5 18 26.12
Mon.	12	23 9 49.4	9.42	0 25.75	0.514	5 22 22.67
Tues.	13	23 13 23.3	+8.40	0 13.34	0.521	5 26 19.23
Wed.	14	23 16 32.7	7.38	0 0.79	0.526	5 30 15.79
Thur.	15	23 19 17.5	6.35	0 11.88	0.530	5 34 12.35
Fri.	16	23 21 37.5	+5.32	0 24.65	0.534	5 38 8.91
Sat.	17	23 23 32.9	4.29	0 37.50	0.537	5 42 5.46
Sun.	18	23 25 3.6	3.26	0 50.40	0.538	5 46 2.02
Mon.	19	23 26 9.5	+2.23	1 3.32	0.539	5 49 58.58
Tues.	20	23 26 50.7	1.20	1 16.25	0.539	5 53 55.14
Wed.	21	23 27 7.1	+0.17	1 29.18	0.538	5 57 51.70
Thur.	22	23 26 58.7	−0.86	1 42.08	0.536	6 1 48.25
Fri.	23	23 26 25.5	1.90	1 54.91	0.533	6 5 44.81
Sat.	24	23 25 27.6	2.93	2 7.68	0.530	6 9 41.37
Sun.	25	23 24 5.0	−3.96	2 20.36	0.526	6 13 37.93
Mon.	26	23 22 17.6	4.99	2 32.93	0.521	6 17 34.48
Tues.	27	23 20 5.6	6.01	2 45.38	0.515	6 21 31.04
Wed.	28	23 17 29.0	−7.04	2 57.67	0.509	6 25 27.60
Thur.	29	23 14 27.9	8.06	3 9.79	0.501	6 29 24.16
Fri.	30	23 11 2.2	9.08	3 21.73	0.493	6 33 20.72
Sat.	31	N 23 7 12.2	−10.09	3 33.45	0.484	6 37 17.27

JUNE, 1899

IV . **Greenwich Mean Time**

Day of the Month	The Moon's Semi-Diameter Noon	Semi-Diameter Midnight	Horizontal Parallax Noon	Diff. for 1 Hour	Horizontal Parallax Midnight	Diff. for 1 Hour	Upper Transit Meridian of Greenwich	Diff. for 1 Hour
	′ ″	′ ″	′ ″	″	′ ″	″	h m	m
1	16 2.3	15 58.4	58 45.2	−1.17	58 30.9	−1.20	19 5.5	2.01
2	15 54.4	15 50.3	58 16.2	1.23	58 1.2	1.25	19 53.8	2.02
3	15 46.2	15 42.1	57 46.1	1.26	57 30.9	1.27	20 42.8	2.07
4	15 38.0	15 33.8	57 15.7	−1.27	57 0.4	−1.27	21 33.3	2.13
5	15 29.6	15 25.5	56 45.2	1.26	56 30.1	1.25	22 25.1	2.18
6	15 21.5	15 17.5	56 15.2	1.23	56 0.5	1.21	23 17.9	2.20
7	15 13.6	15 9.7	55 46.1	−1.18	55 32.1	−1.14	♂	
8	15 6.1	15 2.6	55 18.6	1.10	55 5.8	1.03	0 10.6	2.18
9	14 59.3	14 56.3	54 53.8	0.96	54 42.7	0.87	1 2.1	2.11
10	14 53.6	14 51.3	54 32.8	−0.77	54 24.3	−0.65	1 51.6	2.01
11	14 49.4	14 47.9	54 17.2	0.52	54 11.8	0.37	2 38.6	1.90
12	14 46.9	14 46.5	54 8.2	−0.21	54 6.7	−0.04	3 23.2	1.81
13	14 46.7	14 47.4	54 7.3	+0.14	54 10.1	+0.34	4 5.8	1.74
14	14 48.9	14 51.0	54 15.4	0.54	54 23.1	0.74	4 47.1	1.71
15	14 53.7	14 57.2	54 33.3	0.95	54 45.9	1.16	5 28.1	1.71
16	15 1.3	15 6.1	55 1.1	+1.36	55 18.6	+1.55	6 9.7	1.76
17	15 11.5	15 17.4	55 38.4	1.73	56 0.3	1.90	6 53.1	1.86
18	15 23.9	15 30.7	56 24.0	2.03	56 49.2	2.14	7 39.3	2.00
19	15 37.9	15 45.3	57 15.5	+2.22	57 42.5	+2.25	8 29.3	2.17
20	15 52.6	15 59.9	58 9.6	2.24	58 36.3	2.18	9 23.8	2.37
21	16 6.9	16 13.5	59 2.1	2.07	59 26.1	1.91	10 22.6	2.53
22	16 19.4	16 24.6	59 48.0	+1.70	60 6.9	+1.44	11 24.5	2.61
23	16 28.8	16 32.1	60 22.6	1.15	60 34.5	0.83	12 27.2	2.60
24	16 34.2	16 35.3	60 42.4	+0.48	60 46.2	+0.14	13 28.4	2.49
25	16 35.1	16 33.9	60 45.7	−0.20	60 41.3	−0.53	14 26.5	2.35
26	16 31.7	16 28.6	60 33.1	0.82	60 21.6	1.08	15 21.2	2.21
27	16 24.6	16 20.1	60 7.2	1.30	59 50.4	1.48	16 13.0	2.11
28	16 15.0	16 9.5	59 31.7	−1.61	59 11.6	−1.70	17 2.7	2.05
29	16 3.8	15 58.0	58 50.7	1.76	58 29.3	1.78	17 51.6	2.03
30	15 52.2	15 46.4	58 7.9	1.78	57 46.6	1.75	18 40.6	2.05
31	15 40.7	15 35.3	57 25.9	−1.70	57 5.8	−1.64	19 30.4	2.10

JUNE, 1899

GREENWICH MEAN TIME

The Moon's Right Ascension and Declination

(THURSDAY, 15)

Hour	Right Ascension	Diff. for 1 Minute	Declination	Diff. for 1 Minute
	h m s	s	° ′ ″	″
0	10 53 13.25	1.8257	N 1 35 14.0	12.137
1	10 55 2.81	1.8263	1 23 5.4	12.149
2	10 56 52.41	1.8271	1 10 56.1	12.161
3	10 58 42.06	1.8279	0 58 46.1	12.173
4	11 0 31.76	1.8288	0 46 35.4	12.184
5	11 2 21.51	1.8298	0 34 24.1	12.193
6	11 4 11.33	1.8308	0 22 12.2	12.203
7	11 6 1.20	1.8318	N 0 9 59.8	12.211
8	11 7 51.15	1.8331	S 0 2 13.1	12.219
9	11 9 41.17	1.8343	0 14 26.5	12.227
10	11 11 31.26	1.8355	0 26 40.3	12.234
11	11 13 21.43	1.8368	0 38 54.6	12.240
12	11 15 11.68	1.8383	0 51 9.1	12.245
13	11 17 2.02	1.8398	1 3 24.0	12.250
14	11 18 52.46	1.8414	1 15 39.1	12.254
15	11 20 42.99	1.8430	1 27 54.5	12.258
16	11 22 33.62	1.8448	1 40 10.1	12.261
17	11 24 24.36	1.8466	1 52 25.8	12.263
18	11 26 15.21	1.8484	2 4 41.7	12.265
19	11 28 6.17	1.8503	2 16 57.6	12.265
20	11 29 57.24	1.8523	2 29 13.5	12.266
21	11 31 48.44	1.8544	2 41 29.5	12.266
22	11 33 39.77	1.8565	2 53 45.4	12.264
23	11 35 31.22	1.8587	S 3 6 1.2	12.262

JUNE, 1899
Greenwich Mean Time
The Moon's Right Ascension and Declination
(Friday, 23)

Hour	Right Ascension	Diff. for 1 Minute	Declination	Diff. for 1 Minute
	h m s	s	° ′ ″	″
0	18 1 48.90	2.6723	S 23 21 52.4	3.523
1	18 4 29.22	2.6715	23 18 15.9	3.695
2	18 7 9.48	2.6706	23 14 29.0	3.867
3	18 9 49.69	2.6697	23 10 31.8	4.038
4	18 12 29.84	2.6685	23 6 24.4	4.209
5	18 15 9.91	2.6671	23 2 6.7	4.380
6	18 17 49.89	2.6656	22 57 38.8	4.549
7	18 20 29.78	2.6640	22 53 0.8	4.718
8	18 23 9.57	2.6623	22 48 12.6	4.887
9	18 25 49.25	2.6604	22 43 14.3	5.055
10	18 28 28.82	2.6584	22 38 6.0	5.222
11	18 31 8.26	2.6562	22 32 47.7	5.388
12	18 33 47.56	2.6538	22 27 19.4	5.554
13	18 36 26.72	2.6514	22 21 41.2	5.718
14	18 39 5.73	2.6489	22 15 53.2	5.883
15	18 41 44.59	2.6462	22 9 55.3	6.046
16	18 44 23.28	2.6433	22 3 47.7	6.208
17	18 47 1.79	2.6404	21 57 30.4	6.368
18	18 49 40.13	2.6374	21 51 3.5	6.528
19	18 52 18.28	2.6342	21 44 27.0	6.688
20	18 54 56.23	2.6309	21 37 41.0	6.845
21	18 57 33.99	2.6276	21 30 45.6	7.002
22	19 0 11.54	2.6240	21 23 40.8	7.158
23	19 2 48.87	2.6204	S 21 16 26.7	7.312

JULY, 1899

At Greenwich Apparent Noon

I

Day of the Week	Day of the Month	The Sun's Apparent Right Ascension	Diff. for 1 Hr.	The Sun's Apparent Declination	Diff. for 1 Hr.	The Sun's Semi-Diameter	Equation of Time, to be Added to Apparent Time	Diff. for 1 Hr.
		h m s	s	° ′ ″	″	′ ″	m s	s
Sat.	1	6 40 51.34	10.34	N 23 7 11.6	−10.09	15 46.14	3 33.48	0.484
Sun.	2	6 44 59.42	10.33	23 2 57.2	11.10	15 46.13	3 44.97	0.474
Mon.	3	6 49 7.24	10.32	22 58 18.5	12.11	15 46.12	3 56.20	0.462
Tues.	4	6 53 14.78	10.30	22 53 15.8	−13.11	15 46.12	4 7.16	0.450
Wed.	5	6 57 22.02	10.29	22 47 49.2	14.10	15 46.12	4 17.81	0.437
Thur.	6	7 1 28.94	10.28	22 41 58.7	15.09	15 46.13	4 28.14	0.423
Fri.	7	7 5 35.50	10.26	22 35 44.5	−16.07	15 46.14	4 38.12	0.408
Sat.	8	7 9 41.69	10.25	22 29 6.9	17.05	15 46.16	4 47.73	0.392
Sun.	9	7 13 47.48	10.23	22 22 5.9	18.02	15 46.19	4 56.94	0.375
Mon.	10	7 17 52.86	10.21	22 14 41.8	−18.98	15 46.22	5 5.73	0.357
Tues.	11	7 21 57.80	10.19	22 6 54.7	19.93	15 46.26	5 14.09	0.339
Wed.	12	7 26 2.29	10.17	21 58 44.8	20.87	15 46.30	5 22.00	0.320
Thur.	13	7 30 6.29	10.15	21 50 12.4	−21.81	15 46.35	5 29.43	0.299
Fri.	14	7 34 9.81	10.13	21 41 17.7	22.74	15 46.40	5 36.37	0.278
Sat.	15	7 38 12.82	10.11	21 32 0.8	23.66	15 46.46	5 42.80	0.257
Sun.	16	7 42 15.31	10.09	21 22 21.9	−24.57	15 46.52	5 48.72	0.235
Mon.	17	7 46 17.26	10.07	21 12 21.4	25.47	15 46.59	5 54.10	0.213
Tues.	18	7 50 18.67	10.04	21 1 59.3	26.36	15 46.66	5 58.94	0.190
Wed.	19	7 54 19.53	10.02	20 51 16.0	−27.24	15 46.73	6 3.23	0.167
Thur.	20	7 58 19.83	10.00	20 40 11.6	28.11	15 46.81	6 6.96	0.144
Fri.	21	8 2 19.56	9.97	20 28 46.3	28.98	15 46.89	6 10.13	0.120
Sat.	22	8 6 18.73	9.95	20 17 0.5	−29.83	15 46.97	6 12.73	0.096
Sun.	23	8 10 17.32	9.92	20 4 54.3	30.67	15 47.05	6 14.76	0.072
Mon.	24	8 14 15.33	9.90	19 52 28.0	31.51	15 47.14	6 16.21	0.048
Tues.	25	8 18 12.77	9.88	19 39 41.8	−32.33	15 47.24	6 17.09	0.024
Wed.	26	8 22 9.62	9.85	19 26 35.9	33.14	15 47.33	6 17.38	0.000
Thur.	27	8 26 5.89	9.83	19 13 10.6	33.95	15 47.43	6 17.10	0.024
Fri.	28	8 30 1.58	9.80	18 59 26.2	−34.75	15 47.53	6 16.23	0.048
Sat.	29	8 33 56.68	9.78	18 45 22.9	35.53	15 47.63	6 14.78	0.073
Sun.	30	8 37 51.19	9.76	18 31 1.0	36.30	15 47.74	6 12.74	0.097
Mon.	31	8 41 45.12	9.73	18 16 20.8	37.05	15 47.86	6 10.12	0.121
Tues.	32	8 45 38.46	9.71	N 18 1 22.5	−37.80	15 47.98	6 6.91	0.146

JULY, 1899

II

At Greenwich Mean Noon

Day of the Week	Day of the Month	The Sun's Apparent Declination	The Sun's Diff. for 1 Hour	Equation of Time, to be Subtracted From Mean Time	Diff. for 1 Hour	Sidereal Time, or Right Ascension of Mean Sun
		° ′ ″	″	m s	s	h m s
Sat.	1	N 23 7 12.2	−10.09	3 33.45	0.484	6 37 17.27
Sun.	2	23 2 57.9	11.10	3 44.94	0.473	6 41 13.83
Mon.	3	22 58 19.3	12.11	3 56.17	0.462	6 45 10.39
Tues.	4	22 53 16.7	−13.11	4 7.13	0.450	6 49 6.95
Wed.	5	22 47 50.1	14.10	4 17.78	0.437	6 53 3.50
Thur.	6	22 41 59.8	15.09	4 28.11	0.423	6 57 0.06
Fri.	7	22 35 45.7	−16.07	4 38.09	0.408	7 0 56.62
Sat.	8	22 29 8.2	17.05	4 47.69	0.392	7 4 53.18
Sun.	9	22 22 7.3	18.02	4 56.90	0.375	7 8 49.74
Mon.	10	22 14 43.4	−18.98	5 5.71	0.357	7 12 46.29
Tues.	11	22 6 56.4	19.93	5 14.07	0.339	7 16 42.85
Wed.	12	21 58 46.7	20.87	5 21.97	0.319	7 20 39.41
Thur.	13	21 50 14.4	−21.81	5 29.40	0.299	7 24 35.96
Fri.	14	21 41 19.7	22.74	5 36.34	0.278	7 28 32.52
Sat.	15	21 32 3.0	23.66	5 42.78	0.257	7 32 29.08
Sun.	16	21 22 24.2	−24.57	5 48.69	0.235	7 36 25.64
Mon.	17	21 12 23.8	25.47	5 54.08	0.213	7 40 22.19
Tues.	18	21 2 1.9	26.36	5 58.92	0.190	7 44 18.75
Wed.	19	20 51 18.7	−27.24	6 3.21	0.167	7 48 15.31
Thur.	20	20 40 14.4	28.11	6 6.95	0.144	7 52 11.86
Fri.	21	20 28 49.3	28.98	6 10.12	0.120	7 56 8.42
Sat.	22	20 17 3.6	−29.83	6 12.72	0.097	8 0 4.98
Sun.	23	20 4 57.5	30.67	6 14.75	0.073	8 4 1.53
Mon.	24	19 52 31.2	31.51	6 16.20	0.049	8 7 58.09
Tues.	25	19 39 45.1	−32.33	6 17.08	0.025	8 11 54.65
Wed.	26	19 26 39.3	33.14	6 17.38	0.001	8 15 51.20
Thur.	27	19 13 14.1	33.95	6 17.10	0.024	8 19 47.76
Fri.	28	18 59 29.7	−34.75	6 16.24	0.048	8 23 44.32
Sat.	29	18 45 26.5	35.53	6 14.79	0.073	8 27 40.87
Sun.	30	18 31 4.7	36.30	6 12.75	0.097	8 31 37.43
Mon.	31	18 16 24.5	37.05	6 10.13	0.121	8 35 33.98
Tues.	32	N 18 1 26.3	−37.80	6 6.93	0.146	8 39 30.54

JULY, 1899

GREENWICH MEAN TIME

IV

Day of the Month	The Moon's							
	Semi-Diameter		Horizontal Parallax				Upper Transit	
	Noon	Midnight	Noon	Diff. for 1 Hour	Midnight	Diff. for 1 Hour	Meridian of Greenwich	Diff. for 1 Hour
	′ ″	′ ″	′ ″	″	′ ″	″	h m	m
1	15 40.7	15 35.3	57 25.9	−1.70	57 5.8	−1.64	19 30.4	2.10
2	15 30.0	15 25.0	56 46.5	1.57	56 28.2	−1.49	20 21.3	2.14
3	15 20.3	15 15.8	56 10.8	1.40	55 54.4	−1.32	21 13.2	2.17
4	15 11.6	15 7.7	55 39.0	−1.23	55 24.7	−1.15	22 5.4	2.17
5	15 4.1	15 0.8	55 11.4	1.07	54 59.1	0.98	22 56.9	2.12
6	14 57.7	14 54.9	54 47.8	0.90	54 37.6	0.81	23 46.9	2.04
7	14 52.4	14 50.2	54 28.4	−0.72	54 20.3	−0.62	☌	
8	14 48.3	14 46.8	54 13.4	0.53	54 7.7	0.42	0 34.6	1.94
9	14 45.6	14 44.8	54 3.4	0.30	54 0.5	−0.18	1 20.0	1.84
10	14 44.4	14 44.5	53 59.1	−0.05	53 59.3	+0.10	2 3.3	1.76
11	14 45.1	14 46.1	54 1.4	+0.25	54 5.3	0.41	2 44.9	1.71
12	14 47.7	14 49.9	54 11.2	0.58	54 19.3	0.76	3 25.7	1.69
13	14 52.7	14 56.1	54 29.5	+0.95	54 42.0	+1.14	4 6.5	1.72
14	15 0.1	15 4.8	54 56.8	1.33	55 13.9	1.52	4 48.4	1.78
15	15 10.0	15 15.9	55 33.2	1.70	55 54.8	1.88	5 32.3	1.89
16	15 22.3	15 29.2	56 18.3	+2.03	56 43.6	+2.18	6 19.2	2.04
17	15 36.5	15 44.2	57 10.5	2.29	57 38.5	2.36	7 10.2	2.21
18	15 52.0	15 59.8	58 7.2	2.40	58 36.1	2.39	8 5.5	2.40
19	16 7.6	16 15.1	59 4.6	+2.33	59 32.1	+2.21	9 4.9	2.54
20	16 22.1	16 28.4	59 57.7	2.03	60 20.9	1.80	10 6.8	2.60
21	16 33.8	16 38.2	60 40.9	1.51	60 57.1	1.18	11 9.1	2.57
22	16 41.5	16 43.5	61 9.0	+0.80	61 16.3	+0.40	12 9.8	2.47
23	16 44.1	16 43.4	61 18.6	−0.01	61 16.0	−0.41	13 7.6	2.34
24	16 41.4	16 38.2	61 8.7	0.80	60 56.9	1.15	14 2.4	2.23
25	16 33.9	16 28.6	60 41.1	−1.46	60 21.9	−1.72	14 54.8	2.15
26	16 22.7	16 16.1	59 59.9	1.92	59 35.8	2.07	15 45.8	2.11
27	16 9.1	16 1.9	59 10.2	2.16	58 43.8	2.21	16 36.2	2.10
28	15 54.7	15 47.5	58 17.2	−2.21	57 50.8	−2.17	17 26.8	2.12
29	15 40.5	15 33.8	57 25.1	2.10	57 0.4	2.01	18 18.1	2.15
30	15 27.4	15 21.3	56 36.9	1.90	56 14.9	1.77	19 10.0	2.17
31	15 15.8	15 10.7	55 54.5	1.63	55 35.7	1.49	20 2.0	2.16
32	15 6.1	15 1.9	55 18.7	−1.35	55 3.4	−1.20	20 53.6	2.12

JULY, 1899

GREENWICH MEAN TIME

The Moon's Right Ascension and Declination

(THURSDAY, 20)

Hour	Right Ascension	Diff. for 1 Minute	Declination	Diff. for 1 Minute
	h m s	s	° ′ ″	″
0	17 33 47.98	2.6465	S 23 47 53.7	1.652
1	17 36 26.83	2.6485	23 46 9.4	1.824
2	17 39 5.80	2.6503	23 44 14.8	1.996
3	17 41 44.87	2.6520	23 42 9.9	2.168
4	17 44 24.04	2.6536	23 39 54.7	2.340
5	17 47 3.30	2.6550	23 37 29.1	2.512
6	17 49 42.64	2.6562	23 34 53.3	2.683
7	17 52 22.05	2.6574	23 32 7.1	2.856
8	17 55 1.53	2.6584	23 29 10.6	3.027
9	17 57 41.06	2.6592	23 26 3.8	3.200
10	18 0 20.63	2.6598	23 22 46.6	3.372
11	18 3 0.24	2.6604	23 19 19.1	3.544
12	18 5 39.88	2.6608	23 15 41.3	3.716
13	18 8 19.54	2.6611	23 11 53.2	3.888
14	18 10 59.21	2.6612	23 7 54.7	4.060
15	18 13 38.89	2.6612	23 3 46.0	4.231
16	18 16 18.56	2.6610	22 59 27.0	4.402
17	18 18 58.21	2.6607	22 54 57.8	4.572
18	18 21 37.84	2.6602	22 50 18.3	4.743
19	18 24 17.44	2.6597	22 45 28.6	4.912
20	18 26 57.01	2.6590	22 40 28.8	5.082
21	18 29 36.52	2.6581	22 35 18.8	5.251
22	18 32 15.98	2.6572	22 29 58.7	5.419
23	18 34 55.38	2.6560	22 24 28.5	5.587
24	18 37 34.70	2.6547	S 22 18 48.2	5.755

JULY, 1899

Greenwich Mean Time

The Moon's Right Ascension and Declination

(Saturday, 22)

Hour	Right Ascension	Diff. for 1 Minute	Declination	Diff. for 1 Minute
	h m s	s	° ′ ″	″
0	19 40 38.47	2.5903	S 19 14 40.9	9.485
1	19 43 13.78	2.5865	19 5 7.6	9.624
2	19 45 48.85	2.5826	18 55 26.0	9.762
3	19 48 23.69	2.5787	18 45 36.1	9.899
4	19 50 58.29	2.5746	18 35 38.1	10.035
5	19 53 32.64	2.5704	18 25 31.9	10.169
6	19 56 6.74	2.5662	18 15 17.8	10.301
7	19 58 40.59	2.5620	18 4 55.8	10.431
8	20 1 14.18	2.5577	17 54 26.1	10.560
9	20 3 47.51	2.5533	17 43 48.6	10.688
10	20 6 20.58	2.5490	17 33 3.5	10.814
11	20 8 53.39	2.5445	17 22 10.9	10.937
12	20 11 25.92	2.5400	17 11 11.0	11.059
13	20 13 58.19	2.5355	17 0 3.8	11.180
14	20 16 30.18	2.5309	16 48 49.4	11.299
15	20 19 1.90	2.5264	16 37 27.9	11.416
16	20 21 33.35	2.5217	16 25 59.5	11.531
17	20 24 4.51	2.5170	16 14 24.2	11.644
18	20 26 35.39	2.5124	16 2 42.2	11.756
19	20 29 6.00	2.5077	15 50 53.5	11.866
20	20 31 36.32	2.5029	15 38 58.3	11.973
21	20 34 6.35	2.4982	15 26 56.7	12.079
22	20 36 36.10	2.4934	15 14 48.8	12.183
23	20 39 5.56	2.4887	15 2 34.7	12.286
24	20 41 34.74	2.4839	S 14 50 14.5	12.386

AUGUST, 1899

At Greenwich Apparent Noon

I

Day of the Week	Day of the Month	The Sun's Apparent Right Ascension	Diff. for 1 Hr	The Sun's Apparent Declination	Diff. for 1 Hr.	Semi-Diameter	Equation of Time, to be Added to Subtracted From Apparent Time	Diff. for 1 Hr.
		h m s	s	° ′ ″	″	′ ″	m s	s
Tues.	1	8 45 38.46	9.71	N 18 1 22.5	−37.80	15 47.98	6 6.91	0.146
Wed.	2	8 49 31.21	9.68	17 46 6.5	38.53	15 48.10	6 3.12	0.170
Thur.	3	8 53 23.36	9.66	17 30 33.0	39.25	15 48.23	5 58.73	0.195
Fri.	4	8 57 14.93	9.63	17 14 42.5	−39.95	15 48.36	5 53.75	0.220
Sat.	5	9 1 5.90	9.61	16 58 35.1	40.65	15 48.50	5 48.18	0.244
Sun.	6	9 4 56.27	9.58	16 42 11.3	41.33	15 48.64	5 42.02	0.269
Mon.	7	9 8 46.05	9.56	16 25 31.2	−42.00	15 48.79	5 35.26	0.294
Tues.	8	9 12 35.24	9.53	16 8 35.3	42.65	15 48.94	5 27.91	0.319
Wed.	9	9 16 23.83	9.51	15 51 23.9	43.29	15 49.10	5 19.97	0.343
Thur.	10	9 20 11.84	9.48	15 33 57.3	−43.92	15 49.26	5 11.44	0.368
Fri.	11	9 23 59.26	9.46	15 16 15.8	44.53	15 49.43	5 2.33	0.392
Sat.	12	9 27 46.09	9.44	14 58 19.8	45.13	15 49.60	4 52.64	0.416
Sun.	13	9 31 32.36	9.41	14 40 9.4	−45.72	15 49.77	4 42.38	0.439
Mon.	14	9 35 18.06	9.39	14 21 45.2	46.30	15 49.95	4 31.55	0.463
Tues.	15	9 39 3.19	9.36	14 3 7.4	46.86	15 50.13	4 20.16	0.486
Wed.	16	9 42 47.78	9.34	13 44 16.3	−47.41	15 50.32	4 8.24	0.508
Thur.	17	9 46 31.84	9.32	13 25 12.1	47.93	15 50.51	3 55.77	0.529
Fri.	18	9 50 15.37	9.30	13 5 55.2	48.45	15 50.70	3 42.78	0.551
Sat.	19	9 53 58.39	9.28	12 46 26.0	−48.97	15 50.89	3 29.29	0.572
Sun.	20	9 57 40.92	9.26	12 26 44.6	49.47	15 51.09	3 15.30	0.592
Mon.	21	10 1 22.97	9.24	12 6 51.3	49.96	15 51.28	3 0.83	0.612
Tues.	22	10 5 4.55	9.22	11 46 46.6	−50.43	15 51.48	2 45.90	0.631
Wed.	23	10 8 45.69	9.20	11 26 30.6	50.89	15 51.68	2 30.53	0.649
Thur.	24	10 12 26.40	9.18	11 6 3.6	51.34	15 51.89	2 14.72	0.667
Fri.	25	10 16 6.69	9.17	10 45 26.0	−51.78	15 52.09	1 58.51	0.684
Sat.	26	10 19 46.60	9.15	10 24 38.1	52.21	15 52.30	1 41.91	0.700
Sun.	27	10 23 26.12	9.13	10 3 40.1	52.62	15 52.51	1 24.93	0.715
Mon.	28	10 27 5.29	9.12	9 42 32.4	−53.02	15 52.72	1 7.59	0.730
Tues.	29	10 30 44.11	9.11	9 21 15.4	53.40	15 52.93	0 49.90	0.744
Wed.	30	10 34 22.60	9.09	8 59 49.2	53.77	15 53.15	0 31.89	0.757
Thur.	31	10 38 0.78	9.08	8 38 14.4	54.13	15 53.37	0 13.56	0.770
Fri.	32	10 41 38.66	9.07	N 8 16 31.1	−54.47	15 53.60	0 5.06	0.782

AUGUST, 1899

II. AT GREENWICH MEAN NOON

Day of the Week	Day of the Month	The Sun's Apparent Declination	The Sun's Diff. for 1 Hour	Equation of Time, to be Subtracted From / Added to Mean Time	Diff. for 1 Hour	Sidereal Time, or Right Ascension of Mean Sun
		° ′ ″	″	m s	s	h m s
Tues.	1	N 18 1 26.3	−37.80	6 6.93	0.146	8 39 30.54
Wed.	2	17 46 10.3	38.53	6 3.13	0.170	8 43 27.10
Thur.	3	17 30 36.9	39.25	5 58.75	0.195	8 47 23.65
Fri.	4	17 14 46.4	−39.95	5 53.77	0.220	8 51 20.21
Sat.	5	16 58 39.0	40.65	5 48.20	0.244	8 55 16.76
Sun.	6	16 42 15.1	41.33	5 42.04	0.269	8 59 13.32
Mon.	7	16 25 35.0	−42.00	5 35.29	0.294	9 3 9.87
Tues.	8	16 8 39.1	42.65	5 27.94	0.319	9 7 6.43
Wed.	9	15 51 27.7	43.29	5 20.00	0.343	9 11 2.98
Thur.	10	15 34 1.0	−43.92	5 11.48	0.368	9 14 59.54
Fri.	11	15 16 19.5	44.53	5 2.37	0.392	9 18 56.10
Sat.	12	14 58 23.4	45.13	4 52.68	0.416	9 22 52.65
Sun.	13	14 40 13.0	−45.72	4 42.42	0.439	9 26 49.20
Mon.	14	14 21 48.7	46.30	4 31.59	0.463	9 30 45.76
Tues.	15	14 3 10.7	46.86	4 20.20	0.486	9 34 42.32
Wed.	16	13 44 19.5	−47.41	4 8.27	0.508	9 38 38.87
Thur.	17	13 25 15.2	47.94	3 55.80	0.530	9 42 35.42
Fri.	18	13 5 58.2	48.46	3 42.81	0.552	9 46 31.98
Sat.	19	12 46 28.7	−48.98	3 29.32	0.573	9 50 28.53
Sun.	20	12 26 47.2	49.48	3 15.33	0.593	9 54 25.09
Mon.	21	12 6 53.8	49.97	2 0.86	0.612	9 58 21.64
Tues.	22	11 46 48.8	−50.44	2 45.93	0.631	10 2 18.20
Wed.	23	11 26 32.6	50.90	2 30.55	0.650	10 6 14.75
Thur.	24	11 6 5.5	51.35	2 14.75	0.667	10 10 11.30
Fri.	25	10 45 27.7	−51.79	1 58.53	0.684	10 14 7.86
Sat.	26	10 24 39.5	52.22	1 41.93	0.700	10 18 4.41
Sun.	27	10 3 41.3	52.63	1 24.95	0.715	10 22 0.96
Mon.	28	9 42 33.4	−53.03	1 7.60	0.730	10 25 57.52
Tues.	29	9 21 16.1	53.41	0 49.91	0.744	10 29 54.07
Wed.	30	8 59 49.7	53.78	0 31.90	0.757	10 33 50.62
Thur.	31	8 38 14.5	54.14	0 13.57	0.770	10 37 47.18
Fri.	32	N 8 16 31.0	−54.48	0 5.06	0.782	10 41 43.73

AUGUST, 1899

Greenwich Mean Time

IV.

Day of the Month	The Moon's							
	Semi-Diameter		Horizontal Parallax				Upper Transit	
	Noon	Midnight	Noon	Diff. for 1 Hour	Midnight	Diff. for 1 Hour	Meridian of Greenwich	Diff. for 1 Hour
	′ ″	′ ″	′ ″	″	′ ″	″	h m	m
1	15 6.1	15 1.9	55 18.7	−1.35	55 3.4	−1.20	20 53.6	2.12
2	14 58.2	14 55.0	54 49.8	1.07	54 37.8	0.93	21 43.7	2.05
3	14 52.2	14 49.8	54 27.5	0.80	54 18.7	0.68	22 32.0	1.96
4	14 47.7	14 46.1	54 11.3	−0.55	54 5.4	−0.43	23 17.9	1.87
5	14 44.9	14 44.0	54 0.9	0.32	53 57.7	−0.21	♂	
6	14 43.6	14 43.4	53 55.9	−0.10	53 55.4	+0.02	0 1.8	1.79
7	14 43.7	14 44.3	53 56.3	+0.13	53 58.6	+0.25	0 44.0	1.73
8	14 45.3	14 46.7	54 2.3	0.37	54 7.5	0.50	1 25.1	1.70
9	14 48.6	14 50.9	54 14.3	0.64	54 22.8	0.78	2 5.8	1.70
10	14 53.6	14 56.9	54 32.9	+0.92	54 44.9	+1.08	2 47.1	1.74
11	15 0.7	15 4.9	54 58.7	1.23	55 14.4	1.39	3 29.7	1.82
12	15 9.7	15 15.1	55 32.1	1.55	55 51.6	1.70	4 14.7	1.93
13	15 20.9	15 27.2	56 13.0	+1.85	56 36.1	+1.99	5 2.9	2.08
14	15 33.9	15 41.0	57 0.8	2.11	57 26.8	2.21	5 54.8	2.24
15	15 48.3	15 55.9	57 53.8	2.28	58 21.5	2.31	6 50.5	2.39
16	16 3.4	16 10.9	58 49.3	+2.30	59 16.7	+2.24	7 49.3	2.50
17	16 18.1	16 24.8	59 43.1	2.13	60 7.9	1.96	8 49.9	2.53
18	16 30.9	16 36.1	60 30.2	1.73	60 49.4	1.45	9 50.3	2.49
19	16 40.4	16 43.4	61 4.9	+1.11	61 16.2	+0.74	10 49.2	2.41
20	16 45.2	16 45.6	61 22.6	+0.33	61 24.2	−0.08	11 45.9	2.31
21	16 44.6	16 42.3	61 20.6	−0.50	61 12.1	0.91	12 40.5	2.24
22	16 38.7	16 34.0	60 58.8	−1.28	60 41.4	−1.60	13 33.5	2.19
23	16 28.2	16 21.7	60 20.3	1.88	59 56.2	2.10	14 25.9	2.18
24	16 14.5	16 6.9	59 29.9	2.26	59 2.0	2.36	15 18.2	2.19
25	15 59.1	15 51.2	58 33.3	−2.40	58 4.3	−2.40	16 10.9	2.21
26	15 43.4	15 35.9	57 35.8	2.35	57 8.1	2.26	17 4.0	2.22
27	15 28.7	15 21.9	56 41.6	2.14	56 16.7	2.00	17 57.1	2.20
28	15 15.6	15 9.9	55 53.7	−1.84	55 32.6	−1.67	18 49.5	2.16
29	15 4.7	15 0.2	55 13.7	1.49	54 57.0	1.30	19 40.3	2.08
30	14 56.2	14 52.8	54 42.4	1.12	54 30.0	0.94	20 29.2	1.99
31	14 50.1	14 47.8	54 19.8	0.77	54 11.6	0.60	21 15.8	1.90
32	14 46.1	14 44.9	54 5.4	−0.44	54 1.0	−0.29	22 0.3	1.81

AUGUST, 1899

Greenwich Mean Time

The Moon's Right Ascension and Declination

(Saturday, 19)

Hour	Right Ascension	Diff. for 1 Minute	Declination	Diff. for 1 Minute
	h m s	s	° ′ ″	″
0	20 14 24.97	2.5174	S 16 55 56.9	11.009
1	20 16 55.92	2.5142	16 44 52.7	11.131
2	20 19 26.67	2.5108	16 33 41.2	11.251
3	20 21 57.22	2.5076	16 22 22.6	11.369
4	20 24 27.58	2.5042	16 10 56.9	11.487
5	20 26 57.73	2.5008	15 59 24.2	11.602
6	20 29 27.68	2.4974	15 47 44.6	11.717
7	20 31 57.42	2.4939	15 35 58.2	11.828
8	20 34 26.95	2.4905	15 24 5.2	11.939
9	20 36 56.28	2.4871	15 12 5.5	12.048
10	20 39 25.40	2.4836	14 59 59.4	12.155
11	20 41 54.31	2.4800	14 47 46.9	12.261
12	20 44 23.00	2.4765	14 35 28.1	12.365
13	20 46 51.49	2.4730	14 23 3.1	12.467
14	20 49 19.76	2.4694	14 10 32.1	12.567
15	20 51 47.82	2.4658	13 57 55.1	12.666
16	20 54 15.66	2.4622	13 45 12.2	12.762
17	20 56 43.29	2.4587	13 32 23.6	12.857
18	20 59 10.71	2.4552	13 19 29.3	12.951
19	21 1 37.91	2.4515	13 6 29.5	13.042
20	21 4 4.89	2.4479	12 53 24.2	13.132
21	21 6 31.66	2.4444	12 40 13.7	13.219
22	21 8 58.22	2.4408	12 26 57.9	13.306
23	21 11 24.56	2.4372	S 12 13 37.0	13.390

SEPTEMBER, 1899

At Greenwich Apparent Noon

I

Day of the Week	Day of the Month	The Sun's Apparent Right Ascension	Diff. for 1 Hr.	Apparent Declination	Diff. for 1 Hr.	Semi-Diameter	Equation of Time, to be Subtracted From Apparent Time	Diff. for 1 Hr.
		h m s	s	° ′ ″	″	′ ″	m s	s
Fri.	1	10 41 38.66	9.07	N 8 16 31.1	−54.47	15 53.60	0 5.06	0.782
Sat.	2	10 45 16.25	9.06	7 54 39.8	54.80	15 53.83	0 23.97	0.793
Sun.	3	10 48 53.58	9.05	7 32 40.8	55.12	15 54.06	0 43.14	0.804
Mon.	4	10 52 30.65	9.04	7 10 34.4	−55.42	15 54.29	1 2.57	0.814
Tues.	5	10 56 7.48	9.03	6 48 21.0	55.70	15 54.53	1 22.24	0.824
Wed.	6	10 59 44.08	9.02	6 26 1.0	55.97	15 54.77	1 42.14	0.833
Thur.	7	11 3 20.47	9.01	6 3 34.7	−56.23	15 55.02	2 2.25	0.842
Fri.	8	11 6 56.66	9.00	5 41 2.3	56.47	15 55.27	2 22.56	0.850
Sat.	9	11 10 32.67	8.99	5 18 24.4	56.69	15 55.52	2 43.04	0.857
Sun.	10	11 14 8.51	8.99	4 55 41.1	−56.90	15 55.77	3 3.70	0.864
Mon.	11	11 17 44.20	8.98	4 32 53.0	57.11	15 56.03	3 24.50	0.870
Tues.	12	11 21 19.77	8.98	4 10 0.2	57.29	15 56.29	3 45.43	0.875
Wed.	13	11 24 55.22	8.97	3 47 3.2	−57.46	15 56.56	4 6.48	0.879
Thur.	14	11 28 30.58	8.97	3 24 2.1	57.62	15 56.82	4 27.61	0.883
Fri.	15	11 32 5.86	8.96	3 0 57.4	57.77	15 57.08	4 48.82	0.885
Sat.	16	11 35 41.10	8.96	2 37 49.4	−57.90	15 57.35	5 10.08	0.886
Sun.	17	11 39 16.30	8.96	2 14 38.4	58.02	15 57.62	5 31.37	0.887
Mon.	18	11 42 51.51	8.96	1 51 24.6	58.13	15 57.88	5 52.66	0.887
Tues.	19	11 46 26.73	8.96	1 28 8.5	−58.22	15 58.15	6 13.94	0.886
Wed.	20	11 50 1.99	8.97	1 4 50.2	58.30	15 58.41	6 35.17	0.884
Thur.	21	11 53 37.32	8.97	0 41 30.2	58.37	15 58.68	6 56.34	0.880
Fri.	22	11 57 12.74	8.97	N 0 18 8.7	−58.42	15 58.95	7 17.41	0.875
Sat.	23	12 0 48.27	8.98	S 0 5 13.9	58.46	15 59.22	7 38.37	0.870
Sun.	24	12 4 23.95	8.99	0 28 37.4	58.49	15 59.48	7 59.19	0.864
Mon.	25	12 7 59.78	8.99	0 52 1.3	−58.50	15 59.75	8 19.85	0.857
Tues.	26	12 11 35.80	9.00	1 15 25.3	58.50	16 0.01	8 40.33	0.849
Wed.	27	12 15 12.02	9.01	1 38 49.2	58.49	16 0.28	9 0.60	0.840
Thur.	28	12 18 48.48	9.02	2 2 12.5	−58.46	16 0.55	9 20.65	0.830
Fri.	29	12 22 25.18	9.03	2 25 34.9	58.41	16 0.82	9 40.45	0.820
Sat.	30	12 26 2.14	9.04	2 48 56.1	58.35	16 1.09	9 59.98	0.809
Sun.	31	12 29 39.39	9.05	S 3 12 15.5	−58.27	16 1.37	10 19.23	0.796

SEPTEMBER, 1899

At Greenwich Mean Noon

II

Day of the Week	Day of the Month	The Sun's Apparent Declination	The Sun's Diff. for 1 Hour	Equation of Time, to be Added to Mean Time	Diff. for 1 Hour	Sidereal Time, or Right Ascension of Mean Sun
		° ′ ″	″	m s	s	h m s
Fri.	1	N 8 16 31.0	−54.48	0 5.06	0.782	10 41 43.73
Sat.	2	7 54 39.4	54.81	0 23.97	0.793	10 45 40.29
Sun.	3	7 32 40.1	55.13	0 43.15	0.804	10 49 36.84
Mon.	4	7 10 33.4	−55.43	1 2.58	0.815	10 53 33.39
Tues.	5	6 48 19.7	55.71	1 22.26	0.825	10 57 29.94
Wed.	6	6 25 59.4	55.98	1 42.16	0.834	11 1 26.50
Thur.	7	6 3 32.7	−56.24	2 2.28	0.842	11 5 23.05
Fri.	8	5 41 0.0	56.48	2 22.59	0.850	11 9 19.60
Sat.	9	5 18 21.7	56.70	2 43.08	0.857	11 13 16.16
Sun.	10	4 55 38.2	−56.91	3 3.74	0.864	11 17 12.71
Mon.	11	4 32 49.7	57.12	3 24.55	0.870	11 21 9.26
Tues.	12	4 9 56.6	57.30	3 45.49	0.875	11 25 5.82
Wed.	13	3 46 59.2	−57.47	4 6.54	0.879	11 29 2.37
Thur.	14	3 23 57.8	57.63	4 27.68	0.882	11 32 58.92
Fri.	15	3 0 52.7	57.78	4 48.89	0.885	11 36 55.48
Sat.	16	2 37 44.4	−57.91	5 10.16	0.887	11 40 52.03
Sun.	17	2 14 33.0	58.03	5 31.45	0.887	11 44 48.58
Mon.	18	1 51 18.9	58.14	5 52.75	0.887	11 48 45.13
Tues.	19	1 28 2.4	−58.23	6 14.03	0.886	11 52 41.69
Wed.	20	1 4 43.8	58.31	6 35.26	0.884	11 56 38.24
Thur.	21	0 41 23.4	58.38	6 56.44	0.880	12 0 34.79
Fri.	22	N 0 18 1.6	−58.43	7 17.51	0.876	12 4 31.34
Sat.	23	S 0 5 21.4	58.47	7 38.48	0.871	12 8 27.90
Sun.	24	0 28 45.2	58.50	7 59.30	0.864	12 12 24.45
Mon.	25	0 52 9.4	−58.51	8 19.97	0.857	12 16 21.00
Tues.	26	1 15 33.8	58.51	8 40.45	0.849	12 20 17.55
Wed.	27	1 38 58.0	58.50	9 0.73	0.840	12 24 14.11
Thur.	28	2 2 21.6	−58.47	9 20.78	0.830	12 28 10.66
Fri.	29	2 25 44.4	58.42	9 40.58	0.820	12 32 7.21
Sat.	30	2 49 5.8	58.36	10 0.12	0.808	12 36 3.76
Sun.	31	S 3 12 25.6	−58.28	10 19.37	0.796	12 40 0.32

SEPTEMBER, 1899

Greenwich Mean Time

IV

Day of the Month	The Moon's Semi-Diameter Noon	Semi-Diameter Midnight	Horizontal Parallax Noon	Diff. for 1 Hour	Horizontal Parallax Midnight	Diff. for 1 Hour	Upper Transit Meridian of Greenwich	Diff. for 1 Hour
	′ ″	′ ″	′ ″	″	′ ″	″	h m	m
1	14 46.1	14 44.9	54 5.4	−0.44	54 1.0	−0.29	22 0.3	1.81
2	14 44.2	14 44.0	53 58.4	−0.15	53 57.4	−0.02	22 43.0	1.75
3	14 44.1	14 44.7	53 58.0	+0.11	54 0.0	+0.23	23 24.5	1.71
4	14 45.6	14 46.9	54 3.4	+0.34	54 8.1	+0.44	♂	
5	14 48.5	14 50.4	54 14.0	0.55	54 21.1	0.64	0 5.5	1.71
6	14 52.7	14 55.3	54 29.4	0.74	54 38.9	0.84	0 46.8	1.74
7	14 58.2	15 1.4	54 49.6	+0.94	55 1.5	+1.04	1 29.2	1.80
8	15 5.0	15 8.9	55 14.6	1.14	55 28.9	1.25	2 13.5	1.89
9	15 13.1	15 17.7	55 44.5	1.35	56 1.4	1.46	3 0.3	2.01
10	15 22.7	15 28.0	56 19.6	+1.57	56 39.0	+1.67	3 50.3	2.15
11	15 33.6	15 39.5	56 59.6	1.76	57 21.2	1.84	4 43.5	2.28
12	15 45.6	15 51.9	57 43.7	1.90	58 6.9	1.94	5 39.5	2.38
13	15 58.3	16 4.7	58 30.3	+1.96	58 53.8	+1.94	6 37.4	2.43
14	16 10.9	16 16.9	59 16.8	1.88	59 38.9	1.78	7 35.7	2.42
15	16 22.5	16 27.6	59 59.4	1.63	60 17.9	1.43	8 33.3	2.37
16	16 31.9	16 35.3	60 33.7	+1.18	60 46.2	+0.89	9 29.4	2.31
17	16 37.7	16 39.0	60 55.1	+0.56	60 59.8	+0.21	10 24.1	2.25
18	16 39.1	16 37.9	61 0.1	−0.16	60 55.9	−0.54	11 17.6	2.22
19	16 35.5	16 32.0	60 47.2	−0.90	60 34.2	−1.25	12 10.7	2.21
20	16 27.4	16 21.8	60 17.3	1.55	59 56.9	1.82	13 4.0	2.23
21	16 15.5	16 8.6	59 33.7	2.03	59 8.2	2.19	13 58.0	2.26
22	16 1.2	15 53.6	58 41.2	−2.29	58 13.2	−2.34	14 52.6	2.28
23	15 45.9	15 38.3	57 45.0	2.34	57 17.1	2.29	15 47.3	2.26
24	15 31.0	15 24.0	56 50.1	2.20	56 24.3	2.08	16 41.5	2.23
25	15 17.4	15 11.3	56 0.2	−1.93	55 37.9	−1.76	17 34.0	2.15
26	15 5.9	15 1.0	55 17.9	1.58	55 0.1	1.38	18 24.3	2.04
27	14 56.9	14 53.4	54 44.8	1.17	54 32.0	0.97	19 12.0	1.94
28	14 50.6	14 48.4	54 21.6	−0.76	54 13.7	−0.56	19 57.3	1.84
29	14 46.9	14 46.0	54 8.1	−0.37	54 4.9	−0.18	20 40.5	1.77
30	14 45.7	14 46.0	54 3.8	0.00	54 4.8	+0.16	21 22.4	1.73
31	14 46.8	14 48.0	54 7.7	+0.31	54 12.3	+0.45	22 3.7	1.72

OCTOBER, 1899

At Greenwich Apparent Noon

I

Day of the Week	Day of the Month	The Sun's Apparent Right Ascension	Diff. for 1 Hr.	The Sun's Apparent Declination	Diff. for 1 Hr.	The Sun's Semi-Diameter	Equation of Time, to be Subtracted From Apparent Time	Diff. for 1 Hr.
		h m s	s	° ′ ″	″	′ ″	m s	s
Sun.	1	12 29 39.39	9.05	S 3 12 15.5	−58.27	16 1.37	10 19.23	0.796
Mon.	2	12 33 16.94	9.07	3 35 33.0	58.18	16 1.64	10 38.18	0.783
Tues.	3	12 36 54.82	9.08	3 58 48.0	58.07	16 1.91	10 56.81	0.769
Wed.	4	12 40 33.03	9.09	4 22 0.3	−57.95	16 2.19	11 15.10	0.755
Thur.	5	12 44 11.59	9.11	4 45 9.4	57.81	16 2.47	11 33.04	0.740
Fri.	6	12 47 50.52	9.13	5 8 14.9	57.65	16 2.75	11 50.61	0.724
Sat.	7	12 51 29.84	9.14	5 31 16.5	−57.48	16 3.03	12 7.80	0.708
Sun.	8	12 55 9.56	9.16	5 54 13.8	57.29	16 3.31	12 24.59	0.691
Mon.	9	12 58 49.70	9.18	6 17 6.4	57.09	16 3.60	12 40.96	0.673
Tues.	10	13 2 30.28	9.20	6 39 54.0	−56.87	16 3.88	12 56.89	0.654
Wed.	11	13 6 11.30	9.21	7 2 36.1	56.63	16 4.16	13 12.37	0.635
Thur.	12	13 9 52.80	9.23	7 25 12.4	56.38	16 4.45	13 27.38	0.615
Fri.	13	13 13 34.79	9.26	7 47 42.5	−56.12	16 4.73	13 41.92	0.595
Sat.	14	13 17 17.28	9.28	8 10 6.1	55.84	16 5.01	13 55.93	0.574
Sun.	15	13 21 0.30	9.30	8 32 22.7	55.54	16 5.29	14 9.43	0.551
Mon.	16	13 24 43.88	9.32	8 54 32.1	−55.23	16 5.57	14 22.38	0.528
Tues.	17	13 28 28.01	9.35	9 16 33.9	54.91	16 5.84	14 34.76	0.504
Wed.	18	13 32 12.74	9.37	9 38 27.6	54.57	16 6.12	14 46.55	0.479
Thur.	19	13 35 58.08	9.40	10 0 13.0	−54.21	16 6.39	14 57.74	0.453
Fri.	20	13 39 44.04	9.42	10 21 49.7	53.84	16 6.66	15 8.30	0.426
Sat.	21	13 43 30.66	9.45	10 43 17.2	53.45	16 6.93	15 18.21	0.399
Sun.	22	13 47 17.94	9.48	11 4 35.3	−53.05	16 7.20	15 27.45	0.371
Mon.	23	13 51 5.92	9.51	11 25 43.4	52.63	16 7.46	15 36.01	0.342
Tues.	24	13 54 54.60	9.54	11 46 41.4	52.19	16 7.72	15 43.86	0.312
Wed.	25	13 58 44.01	9.57	12 7 28.7	−51.74	16 7.97	15 50.98	0.282
Thur.	26	14 2 34.15	9.60	12 28 4.8	51.27	16 8.23	15 57.38	0.251
Fri.	27	14 6 25.05	9.63	12 48 29.6	50.78	16 8.48	16 3.02	0.219
Sat.	28	14 10 16.72	9.66	13 8 42.4	−50.28	16 8.74	16 7.89	0.187
Sun.	29	14 14 9.16	9.70	13 28 43.0	49.76	16 8.99	16 11.99	0.154
Mon.	30	14 18 2.40	9.73	13 48 30.9	49.22	16 9.24	16 15.30	0.121
Tues.	31	14 21 56.42	9.76	14 8 5.6	48.66	16 9.49	16 17.82	0.088
Wed.	32	14 25 51.26	9.80	S 14 27 26.8	−48.09	16 9.74	16 19.54	0.055

OCTOBER, 1899

At Greenwich Mean Noon

II

Day of the Week	Day of the Month	The Sun's Apparent Declination	The Sun's Diff. for 1 Hour	Equation of Time, to be Added to Mean Time	Diff. for 1 Hour	Sidereal Time, or Right Ascension of Mean Sun
		° ′ ″	″	m s	s	h m s
Sun.	1	S 3 12 25.6	−58.28	10 19.37	0.796	12 40 0.32
Mon.	2	3 35 43.3	58.19	10 38.32	0.783	12 43 56.87
Tues.	3	3 58 58.6	58.08	10 56.95	0.769	12 47 53.42
Wed.	4	4 22 11.1	−57.96	11 15.24	0.755	12 51 49.98
Thur.	5	4 45 20.5	57.82	11 33.18	0.740	12 55 46.53
Fri.	6	5 8 26.3	57.66	11 50.75	0.724	12 59 43.08
Sat.	7	5 31 28.1	−57.49	12 7.94	0.708	13 3 39.63
Sun.	8	5 54 25.7	57.30	12 24.73	0.691	13 7 36.19
Mon.	9	6 17 18.5	57.10	12 41.10	0.673	13 11 32.74
Tues.	10	6 40 6.3	−56.88	12 57.03	0.654	13 15 29.29
Wed.	11	7 2 48.6	56.64	13 12.51	0.635	13 19 25.85
Thur.	12	7 25 25.0	56.39	13 27.52	0.615	13 23 22.40
Fri.	13	7 47 55.3	−56.13	13 42.05	0.595	13 27 18.95
Sat.	14	8 10 19.0	55.85	13 56.06	0.573	13 31 15.50
Sun.	15	8 32 35.8	55.55	14 9.56	0.551	13 35 12.06
Mon.	16	8 54 45.4	−55.24	14 22.50	0.527	13 39 8.61
Tues.	17	9 16 47.2	54.91	14 34.88	0.503	13 43 5.17
Wed.	18	9 38 41.1	54.57	14 46.67	0.478	13 47 1.72
Thur.	19	10 0 26.6	−54.21	14 57.85	0.453	13 50 58.27
Fri.	20	10 22 3.3	53.84	15 8.40	0.426	13 54 54.83
Sat.	21	10 43 30.9	53.45	15 18.31	0.399	13 58 51.38
Sun.	22	11 4 48.9	−53.05	15 27.54	0.371	14 2 47.93
Mon.	23	11 25 57.1	52.63	15 36.09	0.342	14 6 44.49
Tues.	24	11 46 55.0	52.19	15 43.94	0.312	14 10 41.04
Wed.	25	12 7 42.3	−51.74	15 51.06	0.281	14 14 37.60
Thur.	26	12 28 18.5	51.27	15 57.44	0.250	14 18 34.15
Fri.	27	12 48 43.1	50.78	16 3.07	0.219	14 22 30.70
Sat.	28	13 8 55.9	−50.28	16 7.94	0.187	14 26 27.26
Sun.	29	13 28 56.4	49.76	16 12.03	0.154	14 30 23.81
Mon.	30	13 48 44.2	49.22	16 15.33	0.121	14 34 20.37
Tues.	31	14 8 18.8	48.66	16 17.84	0.088	14 38 16.92
Wed.	32	S 14 27 39.8	−48.09	16 19.55	0.054	14 42 13.48

OCTOBER, 1899

Greenwich Mean Time

IV

Day of the Month	The Moon's Semi-Diameter Noon	Semi-Diameter Midnight	Horizontal Parallax Noon	Diff. for 1 Hour	Horizontal Parallax Midnight	Diff. for 1 Hour	Upper Transit Meridian of Greenwich	Diff. for 1 Hour
	′ ″	′ ″	′ ″	″	′ ″	″	h m	m
1	14 46.8	14 48.1	54 7.7	+0.31	54 12.3	+0.45	22 3.7	1.72
2	14 49.7	14 51.8	54 18.5	0.58	54 26.2	0.69	22 45.1	1.74
3	14 54.2	14 56.9	54 35.1	0.79	54 45.1	0.88	23 27.5	1.80
4	14 59.9	15 3.1	54 56.0	+0.95	55 7.8	+1.01	☌	
5	15 6.5	15 10.1	55 20.3	1.07	55 33.5	1.12	0 11.6	1.89
6	15 13.8	15 17.7	55 47.1	1.16	56 1.3	1.20	0 58.1	2.00
7	15 21.6	15 25.7	56 15.8	+1.23	56 30.8	+1.27	1 47.6	2.13
8	15 29.9	15 34.2	56 46.2	1.30	57 1.9	1.32	2 40.1	2.24
9	15 38.6	15 43.0	57 18.0	1.35	57 34.3	1.37	3 35.1	2.33
10	15 47.5	15 52.2	57 50.8	+1.38	58 7.5	+1.39	4 31.7	2.37
11	15 56.6	16 1.1	58 24.2	1.38	58 40.7	1.36	5 28.6	2.36
12	16 5.5	16 9.7	58 56.8	1.32	59 12.2	1.25	6 24.7	2.31
13	16 13.6	16 17.2	59 26.7	+1.15	59 39.9	+1.03	7 19.3	2.24
14	16 20.3	16 22.9	59 51.4	0.87	60 0.8	0.68	8 12.5	2.19
15	16 24.8	16 26.0	60 7.8	+0.47	60 12.0	+0.22	9 4.6	2.16
16	16 26.3	16 25.7	60 13.1	−0.04	60 11.0	−0.32	9 56.5	2.17
17	16 24.2	16 21.7	60 5.4	0.60	59 56.4	0.89	10 48.8	2.20
18	16 18.4	16 14.2	59 44.2	1.15	59 28.8	1.40	11 42.3	2.26
19	16 9.2	16 3.7	59 10.6	−1.61	58 50.1	−1.79	12 37.1	2.31
20	15 57.6	15 51.1	58 27.7	1.93	58 3.9	2.02	13 32.8	2.33
21	15 44.4	15 37.6	57 39.3	2.06	57 14.4	2.07	14 28.5	2.31
22	15 30.9	15 24.3	56 49.7	−2.03	56 25.7	−1.95	15 23.1	2.24
23	15 18.1	15 12.3	56 2.8	1.85	55 41.4	1.71	16 15.5	2.13
24	15 6.9	15 2.2	55 21.8	1.55	55 4.3	1.36	17 5.1	2.01
25	14 58.0	14 54.6	54 49.1	−1.17	54 36.3	−0.97	17 51.8	1.89
26	14 51.8	14 49.7	54 26.1	0.75	54 18.4	0.53	18 36.1	1.80
27	14 48.3	14 47.7	54 13.4	−0.31	54 11.0	−0.10	19 18.4	1.74
28	14 47.7	14 48.4	54 11.1	+0.11	54 13.7	+0.31	19 59.8	1.71
29	14 49.7	14 51.7	54 18.6	0.50	54 25.7	0.67	20 41.0	1.73
30	14 54.1	14 57.1	54 34.7	0.83	54 45.6	0.97	21 23.0	1.78
31	15 0.5	15 4.2	54 58.0	1.09	55 11.7	1.18	22 6.6	1.86
32	15 8.2	15 12.4	55 26.4	+1.26	55 42.0	+1.32	22 52.7	1.98

OCTOBER, 1899

Greenwich Mean Time

The Moon's Right Ascension and Declination

(Sunday, 15)

Hour	Right Ascension	Diff. for 1 Minute	Declination	Diff. for 1 Minute
	h m s	s	° ′ ″	″
0	22 20 51.41	2.2563	S 5 6 16.5	14.137
1	22 23 6.76	2.2554	4 52 7.3	14.170
2	22 25 22.06	2.2547	4 37 56.1	14.202
3	22 27 37.32	2.2539	4 23 43.0	14.232
4	22 29 52.53	2.2531	4 9 28.2	14.260
5	22 32 7.69	2.2524	3 55 11.8	14.287
6	22 34 22.82	2.2519	3 40 53.7	14.314
7	22 36 37.92	2.2513	3 26 34.1	14.338
8	22 38 52.98	2.2507	3 12 13.1	14.360
9	22 41 8.01	2.2502	2 57 50.9	14.381
10	22 43 23.01	2.2498	2 43 27.4	14.401
11	22 45 37.99	2.2495	2 29 2.8	14.418
12	22 47 52.95	2.2492	2 14 37.2	14.434
13	22 50 7.89	2.2489	2 0 10.7	14.449
14	22 52 22.82	2.2487	1 45 43.3	14.463
15	22 54 37.73	2.2485	1 31 15.1	14.475
16	22 56 52.64	2.2485	1 16 46.3	14.484
17	22 59 7.55	2.2484	1 2 17.0	14.492
18	23 1 22.45	2.2483	0 47 47.2	14.499
19	23 3 37.35	2.2484	0 33 17.1	14.504
20	23 5 52.26	2.2485	0 18 46.7	14.508
21	23 8 7.17	2.2486	S 0 4 16.1	14.511
22	23 10 22.09	2.2488	N 0 10 14.6	14.512
23	23 12 37.03	2.2491	N 0 24 45.3	14.510

OCTOBER, 1899

Greenwich Mean Time

The Moon's Right Ascension and Declination

(Wednesday, 18)

Hour	Right Ascension	Diff. for 1 Minute	Declination	Diff. for 1 Minute
	h m s	s	° ′ ″	″
0	1 4 2.20	2.3134	N 11 42 21.5	12.522
1	1 6 21.07	2.3155	11 54 50.5	12.444
2	1 8 40.06	2.3176	12 7 14.8	12.364
3	1 10 59.18	2.3197	12 19 34.2	12.282
4	1 13 18.42	2.3217	12 31 48.7	12.199
5	1 15 37.79	2.3238	12 43 58.1	12.115
6	1 17 57.28	2.3258	12 56 2.5	12.030
7	1 20 16.89	2.3279	13 8 1.7	11.943
8	1 22 36.63	2.3301	13 19 55.7	11.855
9	1 24 56.50	2.3322	13 31 44.3	11.766
10	1 27 16.50	2.3343	13 43 27.6	11.675
11	1 29 36.62	2.3363	13 55 5.3	11.582
12	1 31 56.86	2.3384	14 6 37.5	11.489
13	1 34 17.23	2.3406	14 18 4.0	11.394
14	1 36 37.73	2.3427	14 29 24.8	11.299
15	1 38 58.35	2.3447	14 40 39.9	11.202
16	1 41 19.10	2.3468	14 51 49.0	11.103
17	1 43 39.97	2.3488	15 2 52.2	11.003
18	1 46 0.96	2.3508	15 13 49.4	10.902
19	1 48 22.07	2.3529	15 24 40.5	10.800
20	1 50 43.31	2.3550	15 35 25.4	10.697
21	1 53 4.67	2.3569	15 46 4.1	10.593
22	1 55 26.14	2.3589	15 56 36.5	10.488
23	1 57 47.74	2.3609	16 7 2.6	10.382
24	2 0 9.45	2.3628	N 16 17 22.3	10.273

NOVEMBER, 1899

At Greenwich Apparent Noon

I

Day of the Week	Day of the Month	The Sun's Apparent Right Ascension	Diff. for 1 Hr.	Apparent Declination	Diff. for 1 Hr.	Semi-Diameter	Equation of Time, to be Subtracted From Apparent Time	Diff. for 1 Hr.
		h m s	s	° ′ ″	″	′ ″	m s	s
Wed.	1	14 25 51.26	9.80	S 14 27 26.8	−48.09	16 9.74	16 19.54	0.055
Thur.	2	14 29 46.90	9.83	14 46 34.0	47.50	16 9.98	16 20.44	0.021
Fri.	3	14 33 43.36	9.86	15 5 26.8	46.89	16 10.23	16 20.54	0.013
Sat.	4	14 37 40.64	9.90	15 24 4.7	−46.26	16 10.47	16 19.82	0.047
Sun.	5	14 41 38.73	9.93	15 42 27.4	45.62	16 10.72	16 18.28	0.081
Mon.	6	14 45 37.65	9.97	16 0 34.5	44.96	16 10.96	16 15.93	0.115
Tues.	7	14 49 37.40	10.00	16 18 25.4	−44.28	16 11.20	16 12.74	0.150
Wed.	8	14 53 37.98	10.04	16 35 59.9	43.58	16 11.44	16 8.73	0.184
Thur.	9	14 57 39.38	10.07	16 53 17.5	42.87	16 11.68	16 3.90	0.219
Fri.	10	15 1 41.61	10.11	17 10 17.8	−42.14	16 11.91	15 58.24	0.253
Sat.	11	15 5 44.68	10.14	17 27 0.4	41.40	16 12.15	15 51.75	0.288
Sun.	12	15 9 48.57	10.17	17 43 24.9	40.64	16 12.38	15 44.43	0.322
Mon.	13	15 13 53.30	10.21	17 59 31.0	−39.86	16 12.60	15 36.28	0.357
Tues.	14	15 17 58.86	10.24	18 15 18.2	39.06	16 12.82	15 27.29	0.392
Wed.	15	15 22 5.26	10.28	18 30 46.2	38.25	16 13.04	15 17.48	0.426
Thur.	16	15 26 12.50	10.31	18 45 54.6	−37.43	16 13.25	15 6.83	0.461
Fri.	17	15 30 20.56	10.35	19 0 42.9	36.59	16 13.46	14 55.35	0.496
Sat.	18	15 34 29.46	10.38	19 15 11.0	35.73	16 13.66	14 43.04	0.531
Sun.	19	15 38 39.20	10.42	19 29 18.2	−34.86	16 13.86	14 29.89	0.565
Mon.	20	15 42 49.76	10.45	19 43 4.4	33.97	16 14.06	14 15.92	0.599
Tues.	21	15 47 1.15	10.49	19 56 29.1	33.07	16 14.25	14 1.14	0.633
Wed.	22	15 51 13.35	10.52	20 9 32.0	−32.15	16 14.43	13 45.53	0.667
Thur.	23	15 55 26.37	10.55	20 22 12.8	31.22	16 14.61	13 29.12	0.700
Fri.	24	15 59 40.18	10.59	20 34 31.0	30.28	16 14.79	13 11.91	0.733
Sat.	25	16 3 54.79	10.62	20 46 26.2	−29.32	16 14.96	12 53.90	0.766
Sun.	26	16 8 10.18	10.65	20 57 58.3	28.34	16 15.13	12 35.13	0.798
Mon.	27	16 12 26.32	10.68	21 9 6.8	27.35	16 15.29	12 15.59	0.829
Tues.	28	16 16 43.20	10.71	21 19 51.4	−26.35	16 15.45	11 55.32	0.859
Wed.	29	16 21 0.81	10.74	21 30 11.8	25.33	16 15.61	11 34.33	0.889
Thur.	30	16 25 19.12	10.77	21 40 7.6	24.30	16 15.76	11 12.64	0.918
Fri.	31	16 29 38.10	10.80	S 21 49 38.6	−23.26	16 15.91	10 50.27	0.945

NOVEMBER, 1899

At Greenwich Mean Noon

II

Day of the Week	Day of the Month	The Sun's Apparent Declination	The Sun's Diff. for 1 Hour	Equation of Time, to be Added to Mean Time	Diff. for 1 Hour	Sidereal Time, or Right Ascension of Mean Sun
		° ′ ″	″	m s	s	h m s
Wed.	1	S 14 27 39.8	−48.09	16 19.55	0.054	14 42 13.48
Thur.	2	14 46 46.9	47.49	16 20.45	0.020	14 46 10.03
Fri.	3	15 5 39.5	46.88	16 20.54	0.014	14 50 6.58
Sat.	4	15 24 17.3	−46.25	16 19.81	0.048	14 54 3.14
Sun.	5	15 42 39.8	45.61	16 18.26	0.082	14 57 59.70
Mon.	6	16 0 46.6	44.95	16 15.89	0.116	15 1 56.25
Tues.	7	16 18 37.4	−44.27	16 12.70	0.150	15 5 52.80
Wed.	8	16 36 11.6	43.57	16 8.68	0.185	15 9 49.36
Thur.	9	16 53 29.0	42.86	16 3.84	0.219	15 13 45.92
Fri.	10	17 10 29.0	−42.13	15 58.17	0.254	15 17 42.47
Sat.	11	17 27 11.3	41.39	15 51.67	0.288	15 21 39.03
Sun.	12	17 43 35.6	40.63	15 44.34	0.322	15 25 35.58
Mon.	13	17 59 41.4	−39.85	15 36.18	0.357	15 29 32.14
Tues.	14	18 15 28.3	39.05	15 27.19	0.392	15 33 28.70
Wed.	15	18 30 55.9	38.24	15 17.37	0.427	15 37 25.25
Thur.	16	18 46 4.0	−37.42	15 6.71	0.462	15 41 21.81
Fri.	17	19 0 52.0	36.58	14 55.23	0.496	15 45 18.36
Sat.	18	19 15 19.7	35.72	14 42.91	0.531	15 49 14.92
Sun.	19	19 29 26.6	−34.85	14 29.76	0.565	15 53 11.48
Mon.	20	19 43 12.5	33.96	14 15.78	0.599	15 57 8.03
Tues.	21	19 56 36.8	33.06	14 0.99	0.633	16 1 4.59
Wed.	22	20 9 39.4	−32.14	13 45.37	0.667	16 5 1.14
Thur.	23	20 22 19.7	31.21	13 28.96	0.701	16 8 57.70
Fri.	24	20 34 37.6	30.27	13 11.75	0.734	16 12 54.26
Sat.	25	20 46 32.5	−29.31	12 53.74	0.766	16 16 50.81
Sun.	26	20 58 4.2	28.33	12 34.96	0.798	16 20 47.37
Mon.	27	21 9 12.4	27.34	12 15.43	0.830	16 24 43.93
Tues.	28	21 19 56.6	−26.34	11 55.15	0.860	16 28 40.48
Wed.	29	21 30 16.6	25.32	11 34.16	0.889	16 32 37.04
Thur.	30	21 40 12.1	24.29	11 12.47	0.917	16 36 33.60
Fri.	31	S 21 49 42.7	−23.25	10 50.11	0.945	16 40 30.16

NOVEMBER, 1899

Greenwich Mean Time

IV

Day of the Month	The Moon's Semi-Diameter Noon	Semi-Diameter Midnight	Horizontal Parallax Noon	Diff. for 1 Hour	Horizontal Parallax Midnight	Diff. for 1 Hour	Upper Transit Meridian of Greenwich	Diff. for 1 Hour
	′ ″	′ ″	′ ″	″	′ ″	″	h m	m
1	15 8.2	15 12.4	55 26.4	+1.26	55 42.0	+1.32	22 52.7	1.98
2	15 16.8	15 21.3	55 58.0	1.35	56 14.4	1.37	23 41.9	2.12
3	15 25.7	15 30.2	56 30.8	1.36	56 47.1	1.34	☌	
4	15 34.5	15 38.6	57 2.9	+1.30	57 18.2	+1.25	0 34.3	2.25
5	15 42.6	15 46.4	57 32.8	1.19	57 46.7	1.12	1 29.6	2.35
6	15 49.9	15 53.2	57 59.6	1.05	58 11.7	0.97	2 26.8	2.40
7	15 56.3	15 59.1	58 22.9	+0.90	58 33.2	+0.82	3 24.3	2.38
8	16 1.6	16 3.9	58 42.6	0.75	58 51.1	0.67	4 20.7	2.31
9	16 6.0	16 7.8	58 58.7	0.60	59 5.3	0.52	5 15.2	2.23
10	16 9.4	16 10.6	59 11.1	+0.43	59 15.6	+0.33	6 7.6	2.15
11	16 11.6	16 12.2	59 19.1	+0.24	59 21.4	+0.13	6 58.6	2.10
12	16 12.4	16 12.2	59 22.2	0.00	59 21.4	−0.13	7 48.7	2.09
13	16 11.5	16 10.3	59 18.9	−0.28	59 14.6	−0.44	8 39.1	2.12
14	16 8.6	16 6.4	59 8.3	0.61	59 0.0	0.78	9 30.5	2.17
15	16 3.5	16 0.2	58 49.7	0.94	58 37.4	1.10	10 23.5	2.25
16	15 56.3	15 52.0	58 23.2	−1.26	58 7.2	−1.39	11 18.2	2.31
17	15 47.2	15 42.2	57 49.8	1.50	57 31.2	1.59	12 13.9	2.33
18	15 36.9	15 31.4	57 11.7	1.65	56 51.6	1.68	13 9.5	2.29
19	15 25.9	15 20.4	56 31.4	−1.68	56 11.4	−1.64	14 3.7	2.21
20	15 15.2	15 10.2	55 52.0	1.58	55 33.6	1.48	14 55.4	2.09
21	15 5.5	15 1.3	55 16.4	1.36	55 0.9	1.22	15 44.0	1.96
22	14 57.5	14 54.3	54 47.2	−1.05	54 35.5	−0.88	16 29.7	1.85
23	14 51.8	14 49.9	54 26.1	0.68	54 19.2	0.46	17 13.1	1.76
24	14 48.7	14 48.2	54 14.9	−0.25	54 13.1	−0.03	17 54.7	1.71
25	14 48.5	14 49.5	54 14.0	+0.19	54 17.6	+0.40	18 35.7	1.70
26	14 51.1	14 53.5	54 23.8	0.62	54 32.5	0.83	19 16.9	1.74
27	14 56.6	15 0.2	54 43.7	1.03	54 57.1	1.20	19 59.3	1.81
28	15 4.4	15 9.1	55 12.5	+1.36	55 29.8	+1.50	20 44.0	1.92
29	15 14.2	15 19.6	55 48.5	1.61	56 8.4	1.69	21 31.8	2.06
30	15 25.3	15 31.0	56 29.1	1.74	56 50.2	1.76	22 23.2	2.22
31	15 36.8	15 42.4	57 11.3	+1.75	57 32.1	+1.70	23 18.2	2.36

NOVEMBER, 1899

Greenwich Mean Time

The Moon's Right Ascension and Declination

(Friday, 24)

Hour	Right Ascension	Diff. for 1 Minute	Declination	Diff. for 1 Minute
	h m s	s	° ′ ″	″
0	9 37 31.43	1.8621	N 9 12 31.9	10.757
1	9 39 23.09	1.8598	9 1 45.5	10.790
2	9 41 14.61	1.8577	8 50 57.1	10.823
3	9 43 6.01	1.8556	8 40 6.8	10.855
4	9 44 57.28	1.8536	8 29 14.5	10.887
5	9 46 48.44	1.8517	8 18 20.3	10.918
6	9 48 39.48	1.8498	8 7 24.3	10.948
7	9 50 30.41	1.8478	7 56 26.5	10.978
8	9 52 21.22	1.8460	7 45 26.9	11.008
9	9 54 11.93	1.8443	7 34 25.6	11.036
10	9 56 2.54	1.8427	7 23 22.6	11.064
11	9 57 53.05	1.8410	7 12 17.9	11.092
12	9 59 43.46	1.8394	7 1 11.6	11.118
13	10 1 33.78	1.8380	6 50 3.7	11.145
14	10 3 24.02	1.8366	6 38 54.2	11.171
15	10 5 14.17	1.8352	6 27 43.2	11.195
16	10 7 4.24	1.8339	6 16 30.8	11.219
17	10 8 54.24	1.8327	6 5 16.9	11.244
18	10 10 44.16	1.8314	5 54 1.5	11.267
19	10 12 34.01	1.8303	5 42 44.8	11.289
20	10 14 23.80	1.8293	5 31 26.8	11.312
21	10 16 13.52	1.8283	5 20 7.4	11.333
22	10 18 3.19	1.8273	5 8 46.8	11.354
23	10 19 52.80	1.8264	4 57 24.9	11.375
24	10 21 42.36	1.8257	N 4 46 1.8	11.394

DECEMBER, 1899

At Greenwich Apparent Noon

I

Day of the Week	Day of the Month	The Sun's Apparent Right Ascension	Diff. for 1 Hr.	Apparent Declination	Diff. for 1 Hr.	Semi-Diameter	Equation of Time, to be Subtracted From / Added to Apparent Time	Diff. for 1 Hr.
		h m s	s	° ′ ″	″	′ ″	m s	s
Fri.	1	16 29 38.10	10.80	S 21 49 38.6	−23.26	16 15.91	10 50.27	0.945
Sat.	2	16 33 57.73	10.83	21 58 44.4	22.21	16 16.06	10 27.26	0.971
Sun.	3	16 38 17.99	10.85	22 7 24.8	21.15	16 16.21	10 3.63	0.997
Mon.	4	16 42 38.85	10.88	22 15 39.6	−20.07	16 16.35	9 39.40	1.021
Tues.	5	16 47 0.27	10.90	22 23 28.3	18.98	16 16.49	9 14.60	1.044
Wed.	6	16 51 22.22	10.92	22 30 50.9	17.88	16 16.63	8 49.27	1.065
Thur.	7	16 55 44.69	10.94	22 37 47.1	−16.78	16 16.76	8 23.43	1.086
Fri.	8	17 0 7.64	10.96	22 44 16.6	15.67	16 16.89	7 57.12	1.105
Sat.	9	17 4 31.03	10.98	22 50 19.4	14.55	16 17.01	7 30.36	1.122
Sun.	10	17 8 54.84	11.00	22 55 55.0	−13.42	16 17.13	7 3.17	1.139
Mon.	11	17 13 19.04	11.01	23 1 3.5	12.28	16 17.25	6 35.61	1.156
Tues.	12	17 17 43.60	11.03	23 5 44.6	11.14	16 17.36	6 7.68	1.171
Wed.	13	17 22 8.49	11.04	23 9 58.2	−9.99	16 17.46	5 39.43	1.184
Thur.	14	17 26 33.69	11.05	23 13 44.2	8.84	16 17.56	5 10.87	1.196
Fri.	15	17 30 59.15	11.06	23 17 2.3	7.68	16 17.66	4 42.04	1.206
Sat.	16	17 35 24.86	11.07	23 19 52.6	−6.52	16 17.75	4 12.97	1.215
Sun.	17	17 39 50.78	11.08	23 22 14.8	5.34	16 17.83	3 43.69	1.224
Mon.	18	17 44 16.89	11.09	23 24 9.0	4.17	16 17.90	3 14.22	1.231
Tues.	19	17 48 43.16	11.09	23 25 35.0	−2.99	16 17.97	2 44.59	1.237
Wed.	20	17 53 9.55	11.10	23 26 32.8	1.81	16 18.03	2 14.84	1.242
Thur.	21	17 57 36.04	11.10	23 27 2.2	−0.64	16 18.09	1 44.99	1.245
Fri.	22	18 2 2.59	11.10	23 27 3.4	+0.54	16 18.14	1 15.07	1.247
Sat.	23	18 6 29.18	11.10	23 26 36.2	1.72	16 18.18	0 45.13	1.248
Sun.	24	18 10 55.76	11.10	23 25 40.7	2.90	16 18.22	0 15.18	1.247
Mon.	25	18 15 22.32	11.10	23 24 16.9	+4.08	16 18.26	0 14.74	1.245
Tues.	26	18 19 48.81	11.10	23 22 24.8	5.26	16 18.29	0 44.58	1.242
Wed.	27	18 24 15.20	11.09	23 20 4.5	6.43	16 18.31	1 14.33	1.237
Thur.	28	18 28 41.44	11.09	23 17 15.9	+7.60	16 18.33	1 43.94	1.230
Fri.	29	18 33 7.51	11.08	23 13 59.3	8.77	16 18.35	2 13.37	1.222
Sat.	30	18 37 33.37	11.07	23 10 14.7	9.94	16 18.36	2 42.59	1.212
Sun.	31	18 41 58.98	11.06	23 6 2.2	11.10	16 18.37	3 11.56	1.201
Mon.	32	18 46 24.31	11.04	S 23 1 22.2	+12.25	16 18.38	3 40.26	1.189

DECEMBER, 1899

At Greenwich Mean Noon

II

Day of the Week	Day of the Month	The Sun's Apparent Declination	The Sun's Diff. for 1 Hour	Equation of Time, to be Added to / Subtracted From Mean Time	Diff. for 1 Hour	Sidereal Time, or Right Ascension of Mean Sun
		° ′ ″	″	m s	s	h m s
Fri.	1	S 21 49 42.7	−23.25	10 50.11	0.945	16 40 30.16
Sat.	2	21 58 48.3	22.20	10 27.10	0.971	16 44 26.72
Sun.	3	22 7 28.3	21.14	10 3.46	0.997	16 48 23.27
Mon.	4	22 15 42.8	−20.06	9 39.23	1.021	16 52 19.83
Tues.	5	22 23 31.2	18.97	9 14.44	1.044	16 56 16.39
Wed.	6	22 30 53.5	17.87	8 49.11	1.065	17 0 12.94
Thur.	7	22 37 49.4	−16.77	8 23.28	1.086	17 4 9.50
Fri.	8	22 44 18.7	15.66	7 56.97	1.106	17 8 6.06
Sat.	9	22 50 21.2	14.54	7 30.22	1.124	17 12 2.62
Sun.	10	22 55 56.6	−13.41	7 3.04	1.141	17 15 59.18
Mon.	11	23 1 4.9	12.27	6 35.48	1.156	17 19 55.73
Tues.	12	23 5 45.8	11.13	6 7.56	1.170	17 23 52.29
Wed.	13	23 9 59.2	−9.98	5 39.32	1.183	17 27 48.85
Thur.	14	23 13 44.9	8.83	5 10.76	1.195	17 31 45.41
Fri.	15	23 17 3.0	7.67	4 41.95	1.206	17 35 41.96
Sat.	16	23 19 53.0	−6.51	4 12.89	1.216	17 39 38.52
Sun.	17	23 22 15.2	5.34	3 43.61	1.224	17 43 35.08
Mon.	18	23 24 9.2	4.17	3 14.15	1.231	17 47 31.64
Tues.	19	23 25 35.1	−2.99	2 44.53	1.237	17 51 28.20
Wed.	20	23 26 32.8	1.81	2 14.79	1.242	17 55 24.76
Thur.	21	23 27 2.2	−0.64	1 44.95	1.245	17 59 21.31
Fri.	22	23 27 3.4	+0.54	1 15.05	1.247	18 3 17.87
Sat.	23	23 26 36.2	1.72	0 45.11	1.247	18 7 14.43
Sun.	24	23 25 40.7	2.90	0 15.18	1.246	18 11 10.99
Mon.	25	23 24 16.9	+4.08	0 14.73	1.245	18 15 7.54
Tues.	26	23 22 24.9	5.26	0 44.57	1.241	18 19 4.10
Wed.	27	23 20 4.6	6.43	1 14.30	1.236	18 23 0.66
Thur.	28	23 17 16.2	+7.60	1 43.90	1.230	18 26 57.22
Fri.	29	23 13 59.7	8.77	2 13.32	1.222	18 30 53.78
Sat.	30	23 10 15.2	9.93	2 42.53	1.212	18 34 50.33
Sun.	31	23 6 2.8	11.09	3 11.50	1.201	18 38 46.89
Mon.	32	S 23 1 22.8	+12.24	3 40.18	1.188	18 42 43.45

DECEMBER, 1899

GREENWICH MEAN TIME

IV

Day of the Month	The Moon's Semi-Diameter: Noon	Semi-Diameter: Midnight	Horizontal Parallax: Noon	Diff. for 1 Hour	Horizontal Parallax: Midnight	Diff. for 1 Hour	Upper Transit: Meridian of Greenwich	Diff. for 1 Hour
	′ ″	′ ″	′ ″	″	′ ″	″	h m	m
1	15 36.8	15 42.4	57 11.3	+1.75	57 32.1	+1.70	23 18.2	2.36
2	15 47.8	15 52.9	57 52.0	1.61	58 10.7	1.50	♂	
3	15 57.6	16 1.8	58 27.9	1.36	58 43.3	1.20	0 16.1	2.45
4	16 5.4	16 8.5	58 56.6	+1.02	59 7.7	+0.83	1 15.2	2.46
5	16 10.8	16 12.6	59 16.5	0.63	59 22.9	0.44	2 13.7	2.41
6	16 13.7	16 14.3	59 27.1	+0.26	59 29.1	+0.09	3 10.3	2.31
7	16 14.3	16 13.8	59 29.2	−0.08	59 27.4	−0.22	4 4.4	2.20
8	16 12.9	16 11.6	59 24.0	0.34	59 19.2	0.45	4 56.1	2.11
9	16 9.9	16 8.0	59 13.1	0.55	59 6.0	0.63	5 46.2	2.07
10	16 5.8	16 3.4	58 57.9	−0.70	58 49.1	−0.77	6 35.7	2.06
11	16 0.8	15 57.9	58 39.5	0.83	58 29.1	0.89	7 25.5	2.10
12	15 54.9	15 51.8	58 18.1	0.94	58 6.5	1.00	8 16.6	2.16
13	15 48.4	15 44.9	57 54.2	−1.05	57 41.2	−1.11	9 9.2	2.23
14	15 41.2	15 37.4	57 27.7	1.15	57 13.5	1.20	10 3.3	2.28
15	15 33.4	15 29.2	56 58.8	1.24	56 43.7	1.28	10 58.2	2.29
16	15 25.0	15 20.8	56 28.2	−1.30	56 12.6	−1.30	11 52.6	2.24
17	15 16.5	15 12.2	55 57.0	1.29	55 41.6	1.27	12 45.3	2.15
18	15 8.3	15 4.3	55 26.6	1.22	55 12.2	1.16	13 35.5	2.03
19	15 0.7	14 57.3	54 58.8	−1.07	54 46.5	−0.97	14 22.8	1.91
20	14 54.4	14 51.8	54 35.6	0.85	54 26.2	0.70	15 7.4	1.81
21	14 49.8	14 48.3	54 18.7	0.54	54 13.2	−0.37	15 49.8	1.74
22	14 47.4	14 47.1	54 9.9	−0.18	54 8.9	+0.02	16 31.0	1.70
23	14 47.5	14 48.6	54 10.4	+0.23	54 14.5	0.45	17 11.7	1.70
24	14 50.4	14 52.9	54 21.1	0.67	54 30.4	0.88	17 52.9	1.75
25	14 56.2	15 0.1	54 42.3	+1.10	54 56.8	+1.31	18 35.8	1.83
26	15 4.7	15 9.9	55 13.7	1.50	55 32.8	1.68	19 21.2	1.96
27	15 15.7	15 22.0	55 54.0	1.84	56 17.0	1.97	20 10.0	2.11
28	15 28.6	15 35.5	56 41.4	+2.07	57 6.7	+2.14	21 2.7	2.28
29	15 42.6	15 49.6	57 32.6	2.16	57 58.5	2.14	21 59.1	2.42
30	15 56.5	16 3.1	58 23.9	2.07	58 48.2	1.95	22 58.3	2.50
31	16 9.3	16 14.8	59 10.7	1.78	59 31.0	1.58	23 58.5	2.51
32	16 19.6	16 23.5	59 48.5	+1.33	60 2.8	+1.05	♂	

DECEMBER, 1899

Greenwich Mean Time

The Moon's Right Ascension and Declination

(Saturday, 23)

Hour	Right Ascension	Diff. for 1 Minute	Declination	Diff. for 1 Minute
	h m s	s	° ′ ″	″
0	10 50 32.53	1.8127	N 1 42 50.9	11.564
1	10 52 21.28	1.8125	1 31 16.8	11.572
2	10 54 10.03	1.8124	1 19 42.3	11.578
3	10 55 58.77	1.8123	1 8 7.4	11.584
4	10 57 47.51	1.8123	0 56 32.2	11.590
5	10 59 36.25	1.8124	0 44 56.6	11.595
6	11 1 25.00	1.8126	0 33 20.8	11.598
7	11 3 13.76	1.8128	0 21 44.8	11.602
8	11 5 2.53	1.8130	N 0 10 8.6	11.605
9	11 6 51.32	1.8133	S 0 1 27.8	11.608
10	11 8 40.13	1.8138	0 13 4.4	11.610
11	11 10 28.97	1.8143	0 24 41.0	11.611
12	11 12 17.84	1.8148	0 36 17.7	11.612
13	11 14 6.74	1.8153	0 47 54.4	11.612
14	11 15 55.68	1.8160	0 59 31.1	11.612
15	11 17 44.66	1.8167	1 11 7.8	11.611
16	11 19 33.68	1.8174	1 22 44.4	11.609
17	11 21 22.75	1.8183	1 34 20.9	11.607
18	11 23 11.88	1.8193	1 45 57.2	11.603
19	11 25 1.06	1.8202	1 57 33.3	11.600
20	11 26 50.30	1.8212	2 9 9.2	11.597
21	11 28 39.60	1.8223	2 20 44.9	11.593
22	11 30 28.97	1.8234	2 32 20.3	11.587
23	11 32 18.41	1.8247	S 2 43 55.3	11.580

PLANETS' ELEMENTS, 1899

Month	Day of Month	Apparent Right Ascension Noon	Variation of R. A. for 1 Hour Noon	Apparent Declination Noon	Variation of Decl. for 1 Hour Noon	Meridian Passage
			Venus			
		h m s	s	° ′ ″	″	h m
January . .	27	17 24 6.22	+9.279	−18 52 16.2	−15.55	20 57.8
	28	17 27 50.46	+9.407	−18 58 24.3	−15.12	20 57.6
	29	17 31 37.73	+9.531	−19 4 21.6	−14.64	20 57.5
			Mars			
		h m s	s	° ′ ″	″	h m
January . .	18	8 8 9.15	−4.275	+24 39 2.0	+14.30	12 14.6
	19	8 6 26.50	−4.275	+24 44 40.0	+13.85	12 9.0
April	9	8 1 40.34	+3.734	+23 3 13.4	−14.43	6 50.9
	10	8 3 10.59	+3.786	+22 57 24.3	−14.68	6 48.5
	11	8 4 42.09	+3.837	+22 51 29.1	−14.93	6 46.1
			Jupiter			
		h m s	s	° ′ ″	″	h m
January . .	5	14 18 44.81	+1.324	−12 36 44.8	−6.31	19 16.5
	6	14 19 16.36	+1.304	−12 39 14.6	−6.19	19 13.1
	7	14 19 47.43	+1.284	−12 41 41.5	−6.06	19 9.7
	12	14 31 19.24	−0.488	−13 25 58.5	+2.81	15 9.0
	13	14 31 7.18	−0.517	−13 24 49.6	+2.94	15 4.9
	14	14 30 54.44	−0.545	−13 23 37.6	+3.07	15 0.7
March . . .	18	14 29 56.71	−0.656	−13 18 18.3	+3.58	14 44.0
	19	14 29 40.66	−0.682	−13 16 50.9	+3.70	14 39.8
	20	14 29 23.98	−0.708	−13 15 20.6	+3.82	14 35.6
	31	14 25 41.95	−0.964	−12 55 47.7	+5.02	13 48.6
April	1	14 25 18.58	−0.984	−12 53 46.1	+5.11	13 44.3
	2	14 24 54.74	−1.003	−12 51 42.2	+5.20	13 40.0
May	3	14 10 21.99	−1.210	−11 37 40.8	+6.08	11 23.6
	4	14 9 53.02	−1.204	−11 35 15.4	+6.04	11 19.2
	5	14 9 24.21	−1.196	−11 32 51.1	+5.99	11 14.8
	19	14 3 9.47	−1.010	−11 1 54.3	+4.93	10 13.5
	20	14 2 45.46	−0.992	−10 59 57.2	+4.82	10 9.2

NOTE.—The sign + indicates north declinations; the sign − indicates south declinations.

The sign + prefixed to the hourly change of declination indicates that north declinations are increasing and south declinations are decreasing. The sign − indicates that north declinations are decreasing and south declinations increasing.

FIXED STARS, 1899

Mean Places For the Beginning of 1899

Name of Star	Magnitude	Right Ascension	Annual Variation	Declination	Annual Variation
		h m s	s	° ′ ″	″
α Andromedæ	2	0 3 9.95	+3.09	+28 31 58.0	+19.8
β Cassiopeiæ	2	0 3 47.19	3.17	+58 35 32.5	19.8
γ Pegasi (*Algenib*)	3	0 8 2.05	3.08	+14 37 19.2	20.0
ι Ceti	3	0 14 16.70	3.05	− 9 23 2.9	19.9
β Hydri	3	0 20 26.56	3.21	−77 49 23.3	20.2
α Cassiopeiæ (*var.*)	2	0 34 46 44	+3.37	+55 59 0.1	+19.7
β Ceti	2	0 38 31.22	3.01	−18 32 27.9	19.7
γ Cassiopeiæ	2	0 50 36.52	3.58	+60 10 11.0	19.5
β Andromedæ	2	1 4 4.54	3.34	+35 5 6.1	19.1
θ¹ Ceti	4	1 18 58.46	2.99	− 8 42 16.2	18.6
α Ursæ Min. (*Polaris*)	2	1 22 8.63	+25.02	+88 46 7.9	+18.7
α Eridani (*Achernar*)	1	1 33 56.78	2.23	−57 44 59.7	18.3
ζ Ceti	4	1 46 28.50	2.96	−10 50 6.6	17.8
β Arietis	3	1 49 3.53	3.30	+20 18 51.5	17.7
γ Andromedæ	2	1 57 41.81	3.66	+41 50 42.3	17.4
α Arietis	2	2 1 28.70	+3.37	+22 59 5.5	+17.1
β Trianguli	3	2 3 31.93	3.55	+34 30 34.6	17.1
ι Cassiopeiæ	4	2 20 43.97	4.87	+66 56 53.9	16.3
γ Ceti	3	2 38 3.96	3.10	+ 2 48 36.5	15.3
α Ceti	2	2 56 59.92	3.13	+ 3 41 36.5	14.2
β Persei (*Algol*) (*var.*)	2	3 1 35.66	+3.88	+40 33 59.2	+14.0
α Persei	2	3 17 6.60	4.26	+49 30 6.0	13.0
ε Eridani	4	3 28 10.27	2.82	− 9 47 59.6	12.3
η Tauri	3	3 41 28.73	3.55	+23 47 33.9	11.3
ζ Persei	3	3 47 46.91	+3.76	+31 35 0.6	10.9
γ Hydri	3	3 48 47.83	−0.98	−74 32 54.4	+10.9
γ Eridani	3	3 53 19.06	+2.79	−13 47 45.1	10.4
c Persei	4	4 1 19.62	4.34	+47 26 34.0	9.8
ε Tauri	4	4 22 43.07	3.49	+18 57 22.9	8.2
α Tauri (*Aldebaran*)	1	4 30 7.45	3.43	+16 18 22.4	7.4
ι Aurigæ	3	4 50 24.93	+3.90	+33 0 22.2	+5.9
β Eridani	3	5 2 53.05	2.94	− 5 13 0.9	4.8
α Aurigæ (*Capella*)	1	5 9 13.62	4.42	+45 53 42.7	3.9
β Orionis (*Rigel*)	1	5 9 41.01	2.88	− 8 19 6.1	4.3
β Tauri	2	5 19 54.40	3.79	+28 31 19.5	3.3
δ Orionis (*var.*)	2	5 26 50.78	+3.06	− 0 22 26.2	+2.8
α Leporis	3	5 28 16.52	2.64	−17 53 40.6	2.7
ε Orionis	2	5 31 5.28	3.04	− 1 15 59.1	2.5
α Columbæ	3	5 35 59.57	2.17	−34 7 41.1	2.0
κ Orionis	2	5 42 57.94	2.84	− 9 42 19.9	1.4

FIXED STARS, 1899

Mean Places for the Beginning of 1899

Name of Star	Magnitude	Right Ascension	Annual Variation	Declination	Annual Variation
		h m s	s	° ′ ″	″
α Orionis . . . (*var.*)	1	5 49 42.21	+3.24	+ 7 23 17.5	+0.9
β Aurigæ	2	5 52 7.23	4.40	+44 56 13.3	0.6
θ Aurigæ	3	5 52 50.08	4.09	+37 12 19.7	+0.5
η Geminorum	3	6 8 46.90	3.62	+22 32 9.9	−0.7
μ Geminorum	3	6 16 51.06	3.63	+22 33 55.2	1.5
α Argûs (*Canopus*) . . .	1	6 21 42.66	+1.33	−52 38 25.6	−1.8
γ Geminorum	2	6 31 52.65	3.46	+16 29 7.7	2.8
α Canis Majoris (*Sirius*) .	1	6 40 41.85	2.64	−16 34 39.3	4.7
ε Canis Majoris	2	6 54 39.41	2.35	−28 50 5.2	4.7
δ Canis Majoris	2	7 4 17.06	+2.43	−26 13 57.8	−5.5
δ Geminorum	3	7 14 5.51	+3.58	+22 10 5.7	−6.3
β Canis Minoris	3	7 21 40.49	3.25	+ 8 29 34.0	7.0
α² Geminorum (*Castor*) .	2	7 28 9.47	3.83	+32 6 36.9	7.6
α Canis Minoris (*Procyon*)	1	7 34 0.91	3.14	+ 5 29 1.6	9.0
β Geminorum (*Pollux*) .	1	7 39 8.20	3.67	+28 16 12.5	8.4
15 Argûs	3	8 3 14.56	+2.55	−24 0 47.2	−10.2
30 Monocerotis	4	8 20 36.82	3.00	− 3 34 36.4	11.5
ε Hydræ	3	8 41 25.70	3.18	+ 6 47 21.7	13.0
ι Ursæ Majoris	3	8 52 17.65	4.12	+48 26 17.4	13.9
β Argûs	2	9 12 5.50	0.67	−69 18 4.1	14.8
ι Argûs	2	9 14 22.98	+1.60	−58 51 3.6	−15.0
α Hydræ	2	9 22 37.47	2.94	− 8 13 15.0	15.4
θ Ursæ Majoris	3	9 26 6.14	4.03	+52 8 15.2	16.2
ε Leonis	3	9 40 7.16	3.41	+24 14 21.3	16.4
α Leonis (*Regulus*). . .	1	10 2 59.63	3.20	+12 27 39.0	17.5
γ¹ Leonis	2	10 14 24.30	+3.31	+20 21 8.9	−18.1
ρ Leonis	4	10 27 29.66	3.16	+ 9 49 34.6	18.4
46 Leonis Minoris . . .	4	10 47 39.87	3.36	+34 45 34.8	19.3
α Ursæ Majoris	2	10 57 29.83	3.74	+62 17 46.6	19.3
δ Leonis	3	11 8 44.28	3.19	+21 4 37.2	19.6
δ Crateris	4	11 14 17.46	+2.99	−14 13 55.8	−19.4
λ Draconis	4	11 25 24.54	3.61	+69 53 18.6	19.8
β Leonis	2	11 43 54.50	3.06	+15 8 11.8	20.1
γ Ursæ Majoris	2	11 48 31.28	3.17	+54 15 22.2	20.0
ε Corvi	3	12 4 55.79	3.08	−22 3 29.0	20.0
γ Corvi	3	12 10 36.69	+3.08	−16 58 52.3	−20.0
η Virginis	4	12 14 44.32	3.06	− 0 6 20.3	20.0
α¹ Crucis	1	12 20 58.71	3.30	−62 32 21.8	20.0
δ² Corvi	3	12 24 38.42	3.10	−15 57 10.7	20.0
β Corvi	3	12 29 4.83	3.14	−22 50 17.9	19.9

FIXED STARS, 1899

Mean Places for the Beginning of 1899

Name of Star	Magnitude	Right Ascension	Annual Variation	Declination	Annual Variation
		h m s	s	° ′ ″	″
γ Virginis	3	12 36 32.56	+3.03	− 0 53 44.7	−19.8
α¹ Canum Venaticorum	3	12 51 18.29	2.81	+38 51 49.3	19.5
ε Virginis	3	12 57 8.99	2.98	+11 30 6.9	19.4
α Virginis (*Spica*)	1	13 19 52.25	3.15	−10 38 3.4	18.8
ζ Virginis	3	13 29 32.76	3.05	− 0 4 46.5	18.5
η Ursæ Majoris	2	13 43 33.75	+2.37	+49 49 1.8	−18.0
η Bootis	3	13 49 52.55	2.85	+18 54 14.2	18.1
β Centauri	1	13 56 41.29	4.18	−59 53 9.5	17.5
α Draconis	4	14 1 39.35	1.62	+64 51 30.1	17.2
α Bootis (*Arcturus*)	1	14 11 3.27	2.73	+19 42 29.2	18.8
α Centauri (*mean*)	1	14 32 44.21	+4.04	−60 25 6.8	−15.0
ε Bootis	2	14 40 34.63	2.62	+27 29 59.5	15.3
α Libræ	3	14 45 17.36	+3.31	−15 37 19.9	15.1
β Ursæ Minoris	2	14 50 59.79	−0.22	+74 34 5.6	14.7
β Bootis	4	14 58 8.52	+2.26	+40 47 19.4	14.3
δ Bootis	3	15 11 25.91	+2.42	+33 41 30.1	−13.5
β Libræ	3	15 11 34.25	+3.22	− 9 0 37.4	13.4
γ Ursæ Minoris	3	15 20 53.24	−0.12	+72 11 36.2	12.8
α Coronæ Borealis	2	15 30 24.71	+2.53	+27 3 16.0	12.2
α Serpentis	3	15 39 17.55	+2.95	+ 6 44 35.4	−11.5
ε Serpentis	4	15 45 46.86	+2.98	+ 4 46 54.2	−11.0
δ Scorpii	2	15 54 21.62	3.54	−22 20 3.6	10.4
β Scorpii	3	15 59 33.80	3.48	−19 31 45.0	10.1
δ Ophiuchi	3	16 9 3.12	3.14	− 3 26 3.6	9.4
τ Herculis	4	16 16 42.30	1.80	+46 33 13.0	8.7
η Draconis	3	16 22 37.52	+0.80	+61 44 33.7	−8.2
α Scorpii (*Antares*)	1	16 23 12.80	3.67	−26 12 28.7	8.2
β Herculis	3	16 25 52.67	2.57	+21 42 34.6	8.0
ζ Ophiuchi	3	16 31 35.80	3.30	−10 21 45.4	7.5
α Trianguli Australis	2	16 37 58.15	6.31	−68 50 31.7	7.0
κ Ophiuchi	3	16 52 53.24	+2.83	+ 9 31 55.2	−5.7
η Ophiuchi	2	17 4 35.06	3.43	−15 36 0.1	4.7
π Herculis	3	17 11 31.78	2.08	+36 55 22.3	4.2
θ Ophiuchi	3	17 15 48.34	3.68	−24 53 56.3	3.9
β Draconis	3	17 28 9.05	1.35	+52 22 33.3	2.7
α Ophiuchi	2	17 30 14.75	+2.78	+12 38 0.3	−2.8
μ Herculis	3	17 42 30.36	2.34	+27 46 46.3	2.2
γ Draconis	2	17 54 15.64	1.39	+51 30 2.1	−0.5
η Serpentis	3	18 16 5.00	3.10	− 2 55 29.2	+0.7
λ Sagittarii	3	18 21 44.24	3.70	−25 28 40.4	1.6

FIXED STARS, 1899

MEAN PLACES FOR THE BEGINNING OF 1899

Name of Star	Magnitude	Right Ascension	Annual Variation	Declination	Annual Variation
		h m s	s	° ′ ″	″
α Lyræ (*Vega*)	1	18 33 31.15	+2.03	+38 41 22.0	+3.1
σ Sagittarii	2	18 49 0.16	3.72	−26 25 20.3	4.1
ζ Aquilæ	3	19 0 46.08	2.75	+13 42 47.5	5.1
δ Draconis	3	19 12 31.99	0.02	+67 29 1.9	6.3
β Cygni	3	19 26 38.90	2.41	+27 44 50.6	7.3
γ Aquilæ	3	19 41 27.48	+2.85	+10 22 1.2	+8.5
δ Cygni	3	19 41 49.13	1.87	+44 53 2.5	8.6
α Aquilæ (*Altair*)	1	19 45 51.33	2.92	+ 8 36 5.0	9.3
θ Aquilæ	3	20 6 5.59	3.09	− 1 7 16.4	10.4
α Capricorni	4	20 12 27.07	3.33	−12 51 28.7	10.9
α Pavonis	2	20 17 40.01	+4.77	−57 3 30.9	+11.2
γ Cygni	2	20 18 36.32	2.15	+39 55 59.5	11.3
β Pavonis	3	20 35 51.67	5.46	−66 33 57.6	12.5
α Cygni	1	20 37 59.34	2.04	+44 55 9.2	12.7
ε Cygni	3	20 42 7.49	2.42	+33 35 30.2	13.3
ν Cygni	4	20 53 24.44	+2.23	+40 46 41.5	+13.7
ζ Cygni	3	21 8 38.19	2.55	+29 48 44.8	14.6
α Cephei	3	21 16 10.18	1.43	+62 9 27.1	15.1
β Aquarii	3	21 26 14.55	3.16	− 6 0 56.3	15.6
β Cephei	3	21 27 21.44	0.79	+70 7 1.9	15.7
ε Pegasi	2	21 39 13.54	+2.94	+ 9 24 42.6	+16.3
α Aquarii	3	22 0 35.79	3.08	− 0 48 38.2	17.3
α Gruis	2	22 1 52.12	3.80	−47 27 0.3	17.2
γ Aquarii	4	22 16 26.37	3.10	− 1 53 46.9	18.0
ζ Pegasi	3	22 36 25.49	2.99	+10 18 14.6	18.7
ι Cephei	3	22 46 4.91	+2.12	+65 40 8.6	+18.8
α Pis. Aust. (*Fomalhaut*)	1	22 52 4.20	3.32	−30 9 27.3	19.0
α Pegasi (*Markab*)	2	22 59 43.76	2.98	+14 39 42.2	19.3
λ Andromedæ	4	23 32 37.18	2.92	+45 54 38.3	19.4
ω Piscium	4	23 54 7.48	+3.07	+ 6 18 14.8	+19.9

TABLE II

Sidereal Into Mean Solar Time

(Subtractive from Sidereal Time Interval.)

Side-real	0^h	1^h	2^h	3^h	4^h	5^h	6^h	7^h	8^h	9^h	10^h	11^h
m	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s
0	0 0.0	0 9.8	0 19.7	0 29.5	0 39.3	0 49.1	0 59.0	1 8.8	1 18.6	1 28.5	1 38.3	1 48.1
1	0 0.2	0 10.0	0 19.8	0 29.7	0 39.5	0 49.3	0 59.1	1 9.0	1 18.8	1 28.6	1 38.5	1 48.3
2	0 0.3	0 10.2	0 20.0	0 29.8	0 39.6	0 49.5	0 59.3	1 9.1	1 19.0	1 28.8	1 38.6	1 48.5
3	0 0.5	0 10.3	0 20.2	0 30.0	0 39.8	0 49.6	0 59.5	1 9.3	1 19.1	1 29.0	1 38.8	1 48.6
4	0 0.7	0 10.5	0 20.3	0 30.1	0 40.0	0 49.8	0 59.6	1 9.5	1 19.3	1 29.1	1 39.0	1 48.8
5	0 0.8	0 10.6	0 20.5	0 30.3	0 40.1	0 50.0	0 59.8	1 9.6	1 19.5	1 29.3	1 39.1	1 48.9
6	0 1.0	0 10.8	0 20.6	0 30.5	0 40.3	0 50.1	1 0.0	1 9.8	1 19.6	1 29.4	1 39.3	1 49.1
7	0 1.1	0 11.0	0 20.8	0 30.6	0 40.5	0 50.3	1 0.1	1 10.0	1 19.8	1 29.6	1 39.4	1 49.3
8	0 1.3	0 11.1	0 21.0	0 30.8	0 40.6	0 50.5	1 0.3	1 10.1	1 19.9	1 29.8	1 39.6	1 49.4
9	0 1.5	0 11.3	0 21.1	0 31.0	0 40.8	0 50.6	1 0.5	1 10.3	1 20.1	1 29.9	1 39.8	1 49.6
10	0 1.6	0 11.5	0 21.3	0 31.1	0 41.0	0 50.8	1 0.6	1 10.4	1 20.3	1 30.1	1 39.9	1 49.8
11	0 1.8	0 11.6	0 21.5	0 31.3	0 41.1	0 51.0	1 0.8	1 10.6	1 20.4	1 30.3	1 40.1	1 49.9
12	0 2.0	0 11.8	0 21.6	0 31.5	0 41.3	0 51.1	1 0.9	1 10.8	1 20.6	1 30.4	1 40.3	1 50.1
13	0 2.1	0 12.0	0 21.8	0 31.6	0 41.4	0 51.3	1 1.1	1 10.9	1 20.8	1 30.6	1 40.4	1 50.3
14	0 2.3	0 12.1	0 22.0	0 31.8	0 41.6	0 51.4	1 1.3	1 11.1	1 20.9	1 30.8	1 40.6	1 50.4
15	0 2.5	0 12.3	0 22.1	0 31.9	0 41.8	0 51.6	1 1.4	1 11.3	1 21.1	1 30.9	1 40.8	1 50.6
16	0 2.6	0 12.5	0 22.3	0 32.1	0 41.9	0 51.8	1 1.6	1 11.4	1 21.3	1 31.1	1 40.9	1 50.7
17	0 2.8	0 12.6	0 22.4	0 32.3	0 42.1	0 51.9	1 1.8	1 11.6	1 21.4	1 31.3	1 41.1	1 50.9
18	0 2.9	0 12.8	0 22.6	0 32.4	0 42.3	0 52.1	1 1.9	1 11.8	1 21.6	1 31.4	1 41.2	1 51.1
19	0 3.1	0 12.9	0 22.8	0 32.6	0 42.4	0 52.3	1 2.1	1 11.9	1 21.7	1 31.6	1 41.4	1 51.2
20	0 3.3	0 13.1	0 22.9	0 32.8	0 42.6	0 52.4	1 2.3	1 12.1	1 21.9	1 31.7	1 41.6	1 51.4
21	0 3.4	0 13.3	0 23.1	0 32.9	0 42.8	0 52.6	1 2.4	1 12.2	1 22.1	1 31.9	1 41.7	1 51.6
22	0 3.6	0 13.4	0 23.3	0 33.1	0 42.9	0 52.8	1 2.6	1 12.4	1 22.2	1 32.1	1 41.9	1 51.7
23	0 3.8	0 13.6	0 23.4	0 33.3	0 43.1	0 52.9	1 2.7	1 12.6	1 22.4	1 32.2	1 42.1	1 51.9
24	0 3.9	0 13.8	0 23.6	0 33.4	0 43.2	0 53.1	1 2.9	1 12.7	1 22.6	1 32.4	1 42.2	1 52.1
25	0 4.1	0 13.9	0 23.8	0 33.6	0 43.4	0 53.2	1 3.1	1 12.9	1 22.7	1 32.6	1 42.4	1 52.2
26	0 4.3	0 14.1	0 23.9	0 33.7	0 43.6	0 53.4	1 3.2	1 13.1	1 22.9	1 32.7	1 42.6	1 52.4
27	0 4.4	0 14.3	0 24.1	0 33.9	0 43.7	0 53.6	1 3.4	1 13.2	1 23.1	1 32.9	1 42.7	1 52.5
28	0 4.6	0 14.4	0 24.2	0 34.1	0 43.9	0 53.7	1 3.6	1 13.4	1 23.2	1 33.1	1 42.9	1 52.7
29	0 4.8	0 14.6	0 24.4	0 34.2	0 44.1	0 53.9	1 3.7	1 13.6	1 23.4	1 33.2	1 43.0	1 52.9
30	0 4.9	0 14.7	0 24.6	0 34.4	0 44.2	0 54.1	1 3.9	1 13.7	1 23.6	1 33.4	1 43.2	1 53.0
31	0 5.1	0 14.9	0 24.7	0 34.6	0 44.4	0 54.2	1 4.1	1 13.9	1 23.7	1 33.5	1 43.4	1 53.2
32	0 5.2	0 15.1	0 24.9	0 34.7	0 44.6	0 54.4	1 4.2	1 14.0	1 23.9	1 33.7	1 43.5	1 53.4
33	0 5.4	0 15.2	0 25.1	0 34.9	0 44.7	0 54.6	1 4.4	1 14.2	1 24.0	1 33.9	1 43.7	1 53.5
34	0 5.6	0 15.4	0 25.2	0 35.1	0 44.9	0 54.7	1 4.5	1 14.4	1 24.2	1 34.0	1 43.9	1 53.7
35	0 5.7	0 15.6	0 25.4	0 35.2	0 45.1	0 54.9	1 4.7	1 14.5	1 24.4	1 34.2	1 44.0	1 53.9
36	0 5.9	0 15.7	0 25.6	0 35.4	0 45.2	0 55.0	1 4.9	1 14.7	1 24.5	1 34.4	1 44.2	1 54.0
37	0 6.1	0 15.9	0 25.7	0 35.6	0 45.4	0 55.2	1 5.0	1 14.9	1 24.7	1 34.5	1 44.4	1 54.2
38	0 6.2	0 16.1	0 25.9	0 35.7	0 45.5	0 55.4	1 5.2	1 15.0	1 24.9	1 34.7	1 44.5	1 54.4
39	0 6.4	0 16.2	0 26.0	0 35.9	0 45.7	0 55.5	1 5.4	1 15.2	1 25.0	1 34.9	1 44.7	1 54.5
40	0 6.6	0 16.4	0 26.2	0 36.0	0 45.9	0 55.7	1 5.5	1 15.4	1 25.2	1 35.0	1 44.8	1 54.7
41	0 6.7	0 16.5	0 26.4	0 36.2	0 46.0	0 55.9	1 5.7	1 15.5	1 25.4	1 35.2	1 45.0	1 54.8
42	0 6.9	0 16.7	0 26.5	0 36.4	0 46.2	0 56.0	1 5.9	1 15.7	1 25.5	1 35.3	1 45.2	1 55.0
43	0 7.0	0 16.9	0 26.7	0 36.5	0 46.4	0 56.2	1 6.0	1 15.9	1 25.7	1 35.5	1 45.3	1 55.2
44	0 7.2	0 17.0	0 26.9	0 36.7	0 46.5	0 56.4	1 6.2	1 16.0	1 25.8	1 35.7	1 45.5	1 55.3
45	0 7.4	0 17.2	0 27.0	0 36.9	0 46.7	0 56.5	1 6.4	1 16.2	1 26.0	1 35.8	1 45.7	1 55.5
46	0 7.5	0 17.4	0 27.2	0 37.0	0 46.9	0 56.7	1 6.5	1 16.3	1 26.2	1 36.0	1 45.8	1 55.7
47	0 7.7	0 17.5	0 27.4	0 37.2	0 47.0	0 56.8	1 6.7	1 16.5	1 26.3	1 36.2	1 46.0	1 55.8
48	0 7.9	0 17.7	0 27.5	0 37.4	0 47.2	0 57.0	1 6.8	1 16.7	1 26.5	1 36.3	1 46.2	1 56.0
49	0 8.0	0 17.9	0 27.7	0 37.5	0 47.3	0 57.2	1 7.0	1 16.8	1 26.7	1 36.5	1 46.3	1 56.2
50	0 8.2	0 18.0	0 27.8	0 37.7	0 47.5	0 57.3	1 7.2	1 17.0	1 26.8	1 36.7	1 46.5	1 56.3
51	0 8.4	0 18.2	0 28.0	0 37.8	0 47.7	0 57.5	1 7.3	1 17.2	1 27.0	1 36.8	1 46.7	1 56.5
52	0 8.5	0 18.3	0 28.2	0 38.0	0 47.8	0 57.7	1 7.5	1 17.3	1 27.2	1 37.0	1 46.8	1 56.6
53	0 8.7	0 18.5	0 28.3	0 38.2	0 48.0	0 57.8	1 7.7	1 17.5	1 27.3	1 37.1	1 47.0	1 56.8
54	0 8.8	0 18.7	0 28.5	0 38.3	0 48.2	0 58.0	1 7.8	1 17.7	1 27.5	1 37.3	1 47.1	1 57.0
55	0 9.0	0 18.8	0 28.7	0 38.5	0 48.3	0 58.2	1 8.0	1 17.8	1 27.6	1 37.5	1 47.3	1 57.1
56	0 9.2	0 19.0	0 28.8	0 38.7	0 48.5	0 58.3	1 8.2	1 18.0	1 27.8	1 37.6	1 47.5	1 57.3
57	0 9.3	0 19.2	0 29.0	0 38.8	0 48.7	0 58.5	1 8.3	1 18.1	1 28.0	1 37.8	1 47.6	1 57.5
58	0 9.5	0 19.3	0 29.2	0 39.0	0 48.8	0 58.6	1 8.5	1 18.3	1 28.1	1 38.0	1 47.8	1 57.6
59	0 9.7	0 19.5	0 29.3	0 39.2	0 49.0	0 58.8	1 8.6	1 18.5	1 28.3	1 38.1	1 48.0	1 57.8

TABLE II

SIDEREAL INTO MEAN SOLAR TIME

(Subtractive from Sidereal Time Interval.)

Side-real	12^h	13^h	14^h	15^h	16^h	17^h	18^h	19^h	20^h	21^h	22^h	23^h
m	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s
0	1 58.0	2 7.8	2 17.6	2 27.4	2 37.3	2 47.1	2 56.9	3 6.8	3 16.6	3 26.4	3 36.2	3 46.1
1	1 58.1	2 7.9	2 17.8	2 27.6	2 37.4	2 47.3	2 57.1	3 6.9	3 16.8	3 26.6	3 36.4	3 46.2
2	1 58.3	2 8.1	2 17.9	2 27.8	2 37.6	2 47.4	2 57.3	3 7.1	3 16.9	3 26.7	3 36.6	3 46.4
3	1 58.4	2 8.3	2 18.1	2 27.9	2 37.8	2 47.6	2 57.4	3 7.2	3 17.1	3 26.9	3 36.7	3 46.6
4	1 58.6	2 8.4	2 18.3	2 28.1	2 37.9	2 47.8	2 57.6	3 7.4	3 17.2	3 27.1	3 36.9	3 46.7
5	1 58.8	2 8.6	2 18.4	2 28.3	2 38.1	2 47.9	2 57.8	3 7.6	3 17.4	3 27.2	3 37.1	3 46.9
6	1 58.9	2 8.8	2 18.6	2 28.4	2 38.3	2 48.0	2 57.9	3 7.7	3 17.6	3 27.4	3 37.2	3 47.1
7	1 59.1	2 8.9	2 18.8	2 28.6	2 38.4	2 48.2	2 58.1	3 7.9	3 17.7	3 27.6	3 37.4	3 47.2
8	1 59.3	2 9.1	2 18.9	2 28.8	2 38.6	2 48.4	2 58.2	3 8.1	3 17.9	3 27.7	3 37.6	3 47.4
9	1 59.4	2 9.3	2 19.1	2 28.9	2 38.7	2 48.6	2 58.4	3 8.2	3 18.1	3 27.9	3 37.7	3 47.6
10	1 59.6	2 9.4	2 19.3	2 29.1	2 38.9	2 48.7	2 58.6	3 8.4	3 18.2	3 28.1	3 37.9	3 47.7
11	1 59.8	2 9.6	2 19.4	2 29.2	2 39.1	2 48.9	2 58.7	3 8.6	3 18.4	3 28.2	3 38.1	3 47.9
12	1 59.9	2 9.8	2 19.6	2 29.4	2 39.2	2 49.1	2 58.9	3 8.7	3 18.6	3 28.4	3 38.2	3 48.0
13	2 0.1	2 9.9	2 19.7	2 29.6	2 39.4	2 49.2	2 59.1	3 8.9	3 18.7	3 28.6	3 38.4	3 48.2
14	2 0.2	2 10.1	2 19.9	2 29.7	2 39.6	2 49.4	2 59.2	3 9.1	3 18.9	3 28.7	3 38.5	3 48.4
15	2 0.4	2 10.2	2 20.1	2 29.9	2 39.7	2 49.6	2 59.4	3 9.2	3 19.0	3 28.9	3 38.7	3 48.5
16	2 0.6	2 10.4	2 20.2	2 30.1	2 39.9	2 49.7	2 59.6	3 9.4	3 19.2	3 29.0	3 38.9	3 48.7
17	2 0.7	2 10.6	2 20.4	2 30.2	2 40.1	2 49.9	2 59.7	3 9.5	3 19.4	3 29.2	3 39.0	3 48.9
18	2 0.9	2 10.7	2 20.6	2 30.4	2 40.2	2 50.1	2 59.9	3 9.7	3 19.5	3 29.4	3 39.2	3 49.0
19	2 1.1	2 10.9	2 20.7	2 30.6	2 40.4	2 50.2	3 0.0	3 9.9	3 19.7	3 29.5	3 39.4	3 49.2
20	2 1.2	2 11.1	2 20.9	2 30.7	2 40.5	2 50.4	3 0.2	3 10.0	3 19.9	3 29.7	3 39.5	3 49.4
21	2 1.4	2 11.2	2 21.1	2 30.9	2 40.7	2 50.5	3 0.4	3 10.2	3 20.0	3 29.9	3 39.7	3 49.5
22	2 1.6	2 11.4	2 21.2	2 31.0	2 40.9	2 50.7	3 0.5	3 10.4	3 20.2	3 30.0	3 39.9	3 49.7
23	2 1.7	2 11.6	2 21.4	2 31.2	2 41.0	2 50.9	3 0.7	3 10.5	3 20.4	3 30.2	3 40.0	3 49.8
24	2 1.9	2 11.7	2 21.5	2 31.4	2 41.2	2 51.0	3 0.9	3 10.7	3 20.5	3 30.4	3 40.2	3 50.0
25	2 2.0	2 11.9	2 21.7	2 31.5	2 41.4	2 51.2	3 1.0	3 10.9	3 20.7	3 30.5	3 40.3	3 50.2
26	2 2.2	2 12.0	2 21.9	2 31.7	2 41.5	2 51.4	3 1.2	3 11.0	3 20.9	3 30.7	3 40.5	3 50.3
27	2 2.4	2 12.2	2 22.0	2 31.9	2 41.7	2 51.5	3 1.4	3 11.2	3 21.0	3 30.8	3 40.7	3 50.5
28	2 2.5	2 12.4	2 22.2	2 32.0	2 41.9	2 51.7	3 1.5	3 11.3	3 21.2	3 31.0	3 40.8	3 50.7
29	2 2.7	2 12.5	2 22.4	2 32.2	2 42.0	2 51.9	3 1.7	3 11.5	3 21.3	3 31.2	3 41.0	3 50.8
30	2 2.9	2 12.7	2 22.5	2 32.4	2 42.2	2 52.0	3 1.8	3 11.7	3 21.5	3 31.3	3 41.2	3 51.0
31	2 3.0	2 12.9	2 22.7	2 32.5	2 42.4	2 52.2	3 2.0	3 11.8	3 21.7	3 31.5	3 41.3	3 51.2
32	2 3.2	2 13.0	2 22.9	2 32.7	2 42.5	2 52.3	3 2.2	3 12.0	3 21.8	3 31.7	3 41.5	3 51.3
33	2 3.4	2 13.2	2 23.0	2 32.8	2 42.7	2 52.5	3 2.3	3 12.2	3 22.0	3 31.8	3 41.7	3 51.5
34	2 3.5	2 13.4	2 23.2	2 33.0	2 42.8	2 52.7	3 2.5	3 12.3	3 22.2	3 32.0	3 41.8	3 51.6
35	2 3.7	2 13.5	2 23.3	2 33.2	2 43.0	2 52.8	3 2.7	3 12.5	3 22.3	3 32.2	3 42.0	3 51.8
36	2 3.9	2 13.7	2 23.5	2 33.3	2 43.2	2 53.0	3 2.8	3 12.7	3 22.5	3 32.3	3 42.1	3 52.0
37	2 4.0	2 13.8	2 23.7	2 33.5	2 43.3	2 53.2	3 3.0	3 12.8	3 22.7	3 32.5	3 42.3	3 52.1
38	2 4.2	2 14.0	2 23.8	2 33.7	2 43.5	2 53.3	3 3.2	3 13.0	3 22.8	3 32.6	3 42.5	3 52.3
39	2 4.3	2 14.2	2 24.0	2 33.8	2 43.7	2 53.5	3 3.3	3 13.2	3 23.0	3 32.8	3 42.6	3 52.5
40	2 4.5	2 14.3	2 24.2	2 34.0	2 43.8	2 53.7	3 3.5	3 13.3	3 23.1	3 33.0	3 42.8	3 52.6
41	2 4.7	2 14.5	2 24.3	2 34.2	2 44.0	2 53.8	3 3.6	3 13.5	3 23.3	3 33.1	3 43.0	3 52.8
42	2 4.8	2 14.7	2 24.5	2 34.3	2 44.2	2 54.0	3 3.8	3 13.6	3 23.5	3 33.3	3 43.1	3 53.0
43	2 5.0	2 14.8	2 24.7	2 34.5	2 44.3	2 54.1	3 4.0	3 13.8	3 23.6	3 33.5	3 43.3	3 53.1
44	2 5.2	2 15.0	2 24.8	2 34.7	2 44.5	2 54.3	3 4.1	3 14.0	3 23.8	3 33.6	3 43.5	3 53.3
45	2 5.3	2 15.2	2 25.0	2 34.8	2 44.6	2 54.5	3 4.3	3 14.1	3 24.0	3 33.8	3 43.6	3 53.5
46	2 5.5	2 15.3	2 25.2	2 35.0	2 44.8	2 54.6	3 4.5	3 14.3	3 24.1	3 34.0	3 43.8	3 53.6
47	2 5.7	2 15.5	2 25.3	2 35.1	2 45.0	2 54.8	3 4.6	3 14.5	3 24.3	3 34.1	3 44.0	3 53.8
48	2 5.8	2 15.6	2 25.5	2 35.3	2 45.1	2 55.0	3 4.8	3 14.6	3 24.5	3 34.3	3 44.1	3 53.9
49	2 6.0	2 15.8	2 25.6	2 35.5	2 45.3	2 55.1	3 5.0	3 14.8	3 24.6	3 34.4	3 44.3	3 54.1
50	2 6.1	2 16.0	2 25.8	2 35.6	2 45.5	2 55.3	3 5.1	3 15.0	3 24.8	3 34.6	3 44.4	3 54.3
51	2 6.3	2 16.1	2 26.0	2 35.8	2 45.6	2 55.5	3 5.3	3 15.1	3 24.9	3 34.8	3 44.6	3 54.4
52	2 6.5	2 16.3	2 26.1	2 36.0	2 45.8	2 55.6	3 5.5	3 15.3	3 25.1	3 34.9	3 44.8	3 54.6
53	2 6.6	2 16.5	2 26.3	2 36.1	2 46.0	2 55.8	3 5.6	3 15.4	3 25.3	3 35.1	3 44.9	3 54.8
54	2 6.8	2 16.6	2 26.5	2 36.3	2 46.1	2 55.9	3 5.8	3 15.6	3 25.4	3 35.3	3 45.1	3 54.9
55	2 7.0	2 16.8	2 26.6	2 36.5	2 46.3	2 56.1	3 5.9	3 15.8	3 25.6	3 35.4	3 45.3	3 55.1
56	2 7.1	2 17.0	2 26.8	2 36.6	2 46.4	2 56.3	3 6.1	3 15.9	3 25.8	3 35.6	3 45.4	3 55.3
57	2 7.3	2 17.1	2 27.0	2 36.8	2 46.6	2 56.4	3 6.3	3 16.1	3 25.9	3 35.8	3 45.6	3 55.4
58	2 7.5	2 17.3	2 27.1	2 36.9	2 46.8	2 56.6	3 6.4	3 16.3	3 26.1	3 35.9	3 45.8	3 55.6
59	2 7.6	2 17.4	2 27.3	2 37.1	2 46.9	2 56.8	3 6.6	3 16.4	3 26.3	3 36.1	3 45.9	3 55.7

TABLE III

Mean Solar Into Sidereal Time

(*Additive to Mean Time Interval.*)

Mean Solar	0^h	1^h	2^h	3^h	4^h	5^h	6^h	7^h	8^h	9^h	10^h	11^h
m	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s
0	0 0.0	0 9.9	0 19.7	0 29.6	0 39.4	0 49.3	0 59.1	1 9.0	1 18.9	1 28.7	1 38.6	1 48.4
1	0 0.2	0 10.0	0 19.9	0 29.7	0 39.6	0 49.4	0 59.3	1 9.2	1 19.0	1 28.9	1 38.7	1 48.6
2	0 0.3	0 10.2	0 20.0	0 29.9	0 39.8	0 49.6	0 59.5	1 9.3	1 19.2	1 29.0	1 38.9	1 48.8
3	0 0.5	0 10.3	0 20.2	0 30.1	0 39.9	0 49.8	0 59.6	1 9.5	1 19.3	1 29.2	1 39.1	1 48.9
4	0 0.7	0 10.5	0 20.4	0 30.2	0 40.1	0 49.9	0 59.8	1 9.7	1 19.5	1 29.4	1 39.2	1 49.1
5	0 0.8	0 10.7	0 20.5	0 30.4	0 40.2	0 50.1	1 0.0	1 9.8	1 19.7	1 29.5	1 39.4	1 49.2
6	0 1.0	0 10.8	0 20.7	0 30.6	0 40.4	0 50.3	1 0.1	1 10.0	1 19.8	1 29.7	1 39.6	1 49.4
7	0 1.2	0 11.0	0 20.9	0 30.7	0 40.6	0 50.4	1 0.3	1 10.1	1 20.0	1 29.9	1 39.7	1 49.6
8	0 1.3	0 11.2	0 21.0	0 30.9	0 40.7	0 50.6	1 0.5	1 10.3	1 20.2	1 30.0	1 39.9	1 49.7
9	0 1.5	0 11.3	0 21.2	0 31.0	0 40.9	0 50.8	1 0.6	1 10.5	1 20.3	1 30.2	1 40.0	1 49.9
10	0 1.6	0 11.5	0 21.4	0 31.2	0 41.1	0 50.9	1 0.8	1 10.6	1 20.5	1 30.4	1 40.2	1 50.1
11	0 1.8	0 11.7	0 21.5	0 31.4	0 41.2	0 51.1	1 0.9	1 10.8	1 20.7	1 30.5	1 40.4	1 50.2
12	0 2.0	0 11.8	0 21.7	0 31.5	0 41.4	0 51.3	1 1.1	1 11.0	1 20.8	1 30.7	1 40.5	1 50.4
13	0 2.1	0 12.0	0 21.8	0 31.7	0 41.6	0 51.4	1 1.3	1 11.1	1 21.0	1 30.8	1 40.7	1 50.6
14	0 2.3	0 12.2	0 22.0	0 31.9	0 41.7	0 51.6	1 1.4	1 11.3	1 21.2	1 31.0	1 40.9	1 50.7
15	0 2.5	0 12.3	0 22.2	0 32.0	0 41.9	0 51.7	1 1.6	1 11.5	1 21.3	1 31.2	1 41.0	1 50.9
16	0 2.6	0 12.5	0 22.3	0 32.2	0 42.1	0 51.9	1 1.8	1 11.6	1 21.5	1 31.3	1 41.2	1 51.0
17	0 2.8	0 12.6	0 22.5	0 32.4	0 42.2	0 52.1	1 1.9	1 11.8	1 21.6	1 31.5	1 41.4	1 51.2
18	0 3.0	0 12.8	0 22.7	0 32.5	0 42.4	0 52.2	1 2.1	1 12.0	1 21.8	1 31.7	1 41.5	1 51.4
19	0 3.1	0 13.0	0 22.8	0 32.7	0 42.5	0 52.4	1 2.3	1 12.1	1 22.0	1 31.8	1 41.7	1 51.5
20	0 3.3	0 13.1	0 23.0	0 32.9	0 42.7	0 52.6	1 2.4	1 12.3	1 22.1	1 32.0	1 41.8	1 51.7
21	0 3.4	0 13.3	0 23.2	0 33.0	0 42.9	0 52.7	1 2.6	1 12.4	1 22.3	1 32.2	1 42.0	1 51.9
22	0 3.6	0 13.5	0 23.3	0 33.2	0 43.0	0 52.9	1 2.8	1 12.6	1 22.5	1 32.3	1 42.2	1 52.0
23	0 3.8	0 13.6	0 23.5	0 33.3	0 43.2	0 53.1	1 2.9	1 12.8	1 22.6	1 32.5	1 42.3	1 52.2
24	0 3.9	0 13.8	0 23.7	0 33.5	0 43.4	0 53.2	1 3.1	1 12.9	1 22.8	1 32.7	1 42.5	1 52.4
25	0 4.1	0 14.0	0 23.8	0 33.7	0 43.5	0 53.4	1 3.2	1 13.1	1 23.0	1 32.8	1 42.7	1 52.5
26	0 4.3	0 14.1	0 24.0	0 33.8	0 43.7	0 53.6	1 3.4	1 13.3	1 23.1	1 33.0	1 42.8	1 52.7
27	0 4.4	0 14.3	0 24.1	0 34.0	0 43.9	0 53.7	1 3.6	1 13.4	1 23.3	1 33.1	1 43.0	1 52.9
28	0 4.6	0 14.5	0 24.3	0 34.2	0 44.0	0 53.9	1 3.7	1 13.6	1 23.5	1 33.3	1 43.2	1 53.0
29	0 4.8	0 14.6	0 24.5	0 34.3	0 44.2	0 54.0	1 3.9	1 13.8	1 23.6	1 33.5	1 43.3	1 53.2
30	0 4.9	0 14.8	0 24.6	0 34.5	0 44.4	0 54.2	1 4.1	1 13.9	1 23.8	1 33.6	1 43.5	1 53.3
31	0 5.1	0 14.9	0 24.8	0 34.7	0 44.5	0 54.4	1 4.2	1 14.1	1 23.9	1 33.8	1 43.7	1 53.5
32	0 5.3	0 15.1	0 25.0	0 34.8	0 44.7	0 54.5	1 4.4	1 14.3	1 24.1	1 34.0	1 43.8	1 53.7
33	0 5.4	0 15.3	0 25.1	0 35.0	0 44.8	0 54.7	1 4.6	1 14.4	1 24.3	1 34.1	1 44.0	1 53.8
34	0 5.6	0 15.4	0 25.3	0 35.2	0 45.0	0 54.9	1 4.7	1 14.6	1 24.4	1 34.3	1 44.2	1 54.0
35	0 5.8	0 15.6	0 25.5	0 35.3	0 45.2	0 55.0	1 4.9	1 14.7	1 24.6	1 34.5	1 44.3	1 54.2
36	0 5.9	0 15.8	0 25.6	0 35.5	0 45.3	0 55.2	1 5.1	1 14.9	1 24.8	1 34.6	1 44.5	1 54.3
37	0 6.1	0 15.9	0 25.8	0 35.6	0 45.5	0 55.4	1 5.2	1 15.1	1 24.9	1 34.8	1 44.6	1 54.5
38	0 6.2	0 16.1	0 26.0	0 35.8	0 45.7	0 55.5	1 5.4	1 15.2	1 25.1	1 35.0	1 44.8	1 54.7
39	0 6.4	0 16.3	0 26.1	0 36.0	0 45.8	0 55.7	1 5.5	1 15.4	1 25.3	1 35.1	1 45.0	1 54.8
40	0 6.6	0 16.4	0 26.3	0 36.1	0 46.0	0 55.9	1 5.7	1 15.6	1 25.4	1 35.3	1 45.1	1 55.0
41	0 6.7	0 16.6	0 26.4	0 36.3	0 46.2	0 56.0	1 5.9	1 15.7	1 25.6	1 35.4	1 45.3	1 55.2
42	0 6.9	0 16.8	0 26.6	0 36.5	0 46.3	0 56.2	1 6.0	1 15.9	1 25.8	1 35.6	1 45.5	1 55.3
43	0 7.1	0 16.9	0 26.8	0 36.6	0 46.5	0 56.3	1 6.2	1 16.1	1 25.9	1 35.8	1 45.6	1 55.5
44	0 7.2	0 17.1	0 26.9	0 36.8	0 46.7	0 56.5	1 6.4	1 16.2	1 26.1	1 35.9	1 45.8	1 55.6
45	0 7.4	0 17.2	0 27.1	0 37.0	0 46.8	0 56.7	1 6.5	1 16.4	1 26.2	1 36.1	1 46.0	1 55.8
46	0 7.6	0 17.4	0 27.3	0 37.1	0 47.0	0 56.8	1 6.7	1 16.6	1 26.4	1 36.3	1 46.1	1 56.0
47	0 7.7	0 17.6	0 27.4	0 37.3	0 47.1	0 57.0	1 6.9	1 16.7	1 26.6	1 36.4	1 46.3	1 56.1
48	0 7.9	0 17.7	0 27.6	0 37.5	0 47.3	0 57.2	1 7.0	1 16.9	1 26.7	1 36.6	1 46.4	1 56.3
49	0 8.0	0 17.9	0 27.8	0 37.6	0 47.5	0 57.3	1 7.2	1 17.0	1 26.9	1 36.8	1 46.6	1 56.5
50	0 8.2	0 18.1	0 27.9	0 37.8	0 47.6	0 57.5	1 7.4	1 17.2	1 27.1	1 36.9	1 46.8	1 56.6
51	0 8.4	0 18.2	0 28.1	0 37.9	0 47.8	0 57.7	1 7.5	1 17.4	1 27.2	1 37.1	1 46.9	1 56.8
52	0 8.5	0 18.4	0 28.3	0 38.1	0 48.0	0 57.8	1 7.7	1 17.5	1 27.4	1 37.3	1 47.1	1 57.0
53	0 8.7	0 18.6	0 28.4	0 38.3	0 48.1	0 58.0	1 7.8	1 17.7	1 27.6	1 37.4	1 47.3	1 57.1
54	0 8.9	0 18.7	0 28.6	0 38.4	0 48.3	0 58.2	1 8.0	1 17.9	1 27.7	1 37.6	1 47.4	1 57.3
55	0 9.0	0 18.9	0 28.7	0 38.6	0 48.5	0 58.3	1 8.2	1 18.0	1 27.9	1 37.7	1 47.6	1 57.5
56	0 9.2	0 19.1	0 28.9	0 38.8	0 48.6	0 58.5	1 8.3	1 18.2	1 28.1	1 37.9	1 47.8	1 57.6
57	0 9.4	0 19.2	0 29.1	0 38.9	0 48.8	0 58.6	1 8.5	1 18.4	1 28.2	1 38.1	1 47.9	1 57.8
58	0 9.5	0 19.4	0 29.2	0 39.1	0 49.0	0 58.8	1 8.7	1 18.5	1 28.4	1 38.2	1 48.1	1 57.9
59	0 9.7	0 19.5	0 29.4	0 39.3	0 49.1	0 59.0	1 8.8	1 18.7	1 28.5	1 38.4	1 48.3	1 58.1

TABLE III

Mean Solar into Sidereal Time

(Additive to Mean Time Interval.)

Mean Solar	12^h	13^h	14^h	15^h	16^h	17^h	18^h	19^h	20^h	21^h	22^h	23^h
m	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s
0	1 58.3	2 8.1	2 18.0	2 27.8	2 37.7	2 47.6	2 57.4	3 7.3	3 17.1	3 27.0	3 36.8	3 46.7
1	1 58.4	2 8.3	2 18.2	2 28.0	2 37.9	2 47.7	2 57.6	3 7.4	3 17.3	3 27.2	3 37.0	3 46.9
2	1 58.6	2 8.5	2 18.3	2 28.2	2 38.0	2 47.9	2 57.7	3 7.6	3 17.5	3 27.3	3 37.2	3 47.0
3	1 58.8	2 8.6	2 18.5	2 28.3	2 38.2	2 48.1	2 57.9	3 7.8	3 17.6	3 27.5	3 37.3	3 47.2
4	1 58.9	2 8.8	2 18.6	2 28.5	2 38.4	2 48.2	2 58.1	3 7.9	3 17.8	3 27.6	3 37.5	3 47.4
5	1 59.1	2 9.0	2 18.8	2 28.7	2 38.5	2 48.4	2 58.2	3 8.1	3 18.0	3 27.8	3 37.7	3 47.5
6	1 59.3	2 9.1	2 19.0	2 28.8	2 38.7	2 48.5	2 58.4	3 8.3	3 18.1	3 28.0	3 37.8	3 47.7
7	1 59.4	2 9.3	2 19.1	2 29.0	2 38.9	2 48.7	2 58.6	3 8.4	3 18.3	3 28.1	3 38.0	3 47.8
8	1 59.6	2 9.4	2 19.3	2 29.2	2 39.0	2 48.9	2 58.7	3 8.6	3 18.4	3 28.3	3 38.2	3 48.0
9	1 59.8	2 9.6	2 19.5	2 29.3	2 39.2	2 49.0	2 58.9	3 8.8	3 18.6	3 28.5	3 38.3	3 48.2
10	1 59.9	2 9.8	2 19.6	2 29.5	2 39.3	2 49.2	2 59.1	3 8.9	3 18.8	3 28.6	3 38.5	3 48.3
11	2 0.1	2 9.9	2 19.8	2 29.7	2 39.5	2 49.4	2 59.2	3 9.1	3 18.9	3 28.8	3 38.6	3 48.5
12	2 0.2	2 10.1	2 20.0	2 29.8	2 39.7	2 49.5	2 59.4	3 9.2	3 19.1	3 29.0	3 38.8	3 48.7
13	2 0.4	2 10.3	2 20.1	2 30.0	2 39.8	2 49.7	2 59.6	3 9.4	3 19.3	3 29.1	3 39.0	3 48.8
14	2 0.6	2 10.4	2 20.3	2 30.1	2 40.0	2 49.9	2 59.7	3 9.6	3 19.4	3 29.3	3 39.1	3 49.0
15	2 0.7	2 10.6	2 20.5	2 30.3	2 40.2	2 50.0	2 59.9	3 9.7	3 19.6	3 29.4	3 39.3	3 49.2
16	2 0.9	2 10.8	2 20.6	2 30.5	2 40.3	2 50.2	3 0.0	3 9.9	3 19.8	3 29.6	3 39.5	3 49.3
17	2 1.1	2 10.9	2 20.8	2 30.6	2 40.5	2 50.4	3 0.2	3 10.1	3 19.9	3 29.8	3 39.6	3 49.5
18	2 1.2	2 11.1	2 20.9	2 30.8	2 40.7	2 50.5	3 0.4	3 10.2	3 20.1	3 29.9	3 39.8	3 49.7
19	2 1.4	2 11.3	2 21.1	2 31.0	2 40.8	2 50.7	3 0.5	3 10.4	3 20.3	3 30.1	3 40.0	3 49.8
20	2 1.6	2 11.4	2 21.3	2 31.1	2 41.0	2 50.8	3 0.7	3 10.6	3 20.4	3 30.3	3 40.1	3 50.0
21	2 1.7	2 11.6	2 21.4	2 31.3	2 41.2	2 51.0	3 0.9	3 10.7	3 20.6	3 30.4	3 40.3	3 50.1
22	2 1.9	2 11.7	2 21.6	2 31.5	2 41.3	2 51.2	3 1.0	3 10.9	3 20.7	3 30.6	3 40.5	3 50.3
23	2 2.1	2 11.9	2 21.8	2 31.6	2 41.5	2 51.3	3 1.2	3 11.1	3 20.9	3 30.8	3 40.6	3 50.5
24	2 2.2	2 12.1	2 21.9	2 31.8	2 41.6	2 51.5	3 1.4	3 11.2	3 21.1	3 30.9	3 40.8	3 50.6
25	2 2.4	2 12.2	2 22.1	2 32.0	2 41.8	2 51.7	3 1.5	3 11.4	3 21.2	3 31.1	3 40.9	3 50.8
26	2 2.5	2 12.4	2 22.3	2 32.1	2 42.0	2 51.8	3 1.7	3 11.5	3 21.4	3 31.3	3 41.1	3 51.0
27	2 2.7	2 12.6	2 22.4	2 32.3	2 42.1	2 52.0	3 1.9	3 11.7	3 21.6	3 31.4	3 41.3	3 51.1
28	2 2.9	2 12.7	2 22.6	2 32.4	2 42.3	2 52.2	3 2.0	3 11.9	3 21.7	3 31.6	3 41.4	3 51.3
29	2 3.0	2 12.9	2 22.8	2 32.6	2 42.5	2 52.3	3 2.2	3 12.0	3 21.9	3 31.8	3 41.6	3 51.5
30	2 3.2	2 13.1	2 22.9	2 32.8	2 42.6	2 52.5	3 2.3	3 12.2	3 22.1	3 31.9	3 41.8	3 51.6
31	2 3.4	2 13.2	2 23.1	2 32.9	2 42.8	2 52.7	3 2.5	3 12.4	3 22.2	3 32.1	3 41.9	3 51.8
32	2 3.5	2 13.4	2 23.2	2 33.1	2 43.0	2 52.8	3 2.7	3 12.5	3 22.4	3 32.2	3 42.1	3 52.0
33	2 3.7	2 13.6	2 23.4	2 33.3	2 43.1	2 53.0	3 2.8	3 12.7	3 22.6	3 32.4	3 42.3	3 52.1
34	2 3.9	2 13.7	2 23.6	2 33.4	2 43.3	2 53.1	3 3.0	3 12.9	3 22.7	3 32.6	3 42.4	3 52.3
35	2 4.0	2 13.9	2 23.7	2 33.6	2 43.5	2 53.3	3 3.2	3 13.0	3 22.9	3 32.7	3 42.6	3 52.4
36	2 4.2	2 14.0	2 23.9	2 33.8	2 43.6	2 53.5	3 3.3	3 13.2	3 23.0	3 32.9	3 42.8	3 52.6
37	2 4.4	2 14.2	2 24.1	2 33.9	2 43.8	2 53.6	3 3.5	3 13.4	3 23.2	3 33.1	3 42.9	3 52.8
38	2 4.5	2 14.4	2 24.2	2 34.1	2 43.9	2 53.8	3 3.7	3 13.5	3 23.4	3 33.2	3 43.1	3 52.9
39	2 4.7	2 14.5	2 24.4	2 34.3	2 44.1	2 54.0	3 3.8	3 13.7	3 23.5	3 33.4	3 43.2	3 53.1
40	2 4.8	2 14.7	2 24.6	2 34.4	2 44.3	2 54.1	3 4.0	3 13.8	3 23.7	3 33.6	3 43.4	3 53.3
41	2 5.0	2 14.9	2 24.7	2 34.6	2 44.4	2 54.3	3 4.2	3 14.0	3 23.9	3 33.7	3 43.6	3 53.4
42	2 5.2	2 15.0	2 24.9	2 34.7	2 44.6	2 54.5	3 4.3	3 14.2	3 24.0	3 33.9	3 43.7	3 53.6
43	2 5.3	2 15.2	2 25.1	2 34.9	2 44.8	2 54.6	3 4.5	3 14.3	3 24.2	3 34.0	3 43.9	3 53.8
44	2 5.5	2 15.4	2 25.2	2 35.1	2 44.9	2 54.8	3 4.6	3 14.5	3 24.4	3 34.2	3 44.1	3 53.9
45	2 5.7	2 15.5	2 25.4	2 35.2	2 45.1	2 55.0	3 4.8	3 14.7	3 24.5	3 34.4	3 44.2	3 54.1
46	2 5.8	2 15.7	2 25.5	2 35.4	2 45.3	2 55.1	3 5.0	3 14.8	3 24.7	3 34.5	3 44.4	3 54.3
47	2 6.0	2 15.9	2 25.7	2 35.6	2 45.4	2 55.3	3 5.1	3 15.0	3 24.8	3 34.7	3 44.6	3 54.4
48	2 6.2	2 16.0	2 25.9	2 35.7	2 45.6	2 55.4	3 5.3	3 15.2	3 25.0	3 34.9	3 44.7	3 54.6
49	2 6.3	2 16.2	2 26.0	2 35.9	2 45.8	2 55.6	3 5.5	3 15.3	3 25.2	3 35.0	3 44.9	3 54.7
50	2 6.5	2 16.3	2 26.2	2 36.1	2 45.9	2 55.8	3 5.6	3 15.5	3 25.3	3 35.2	3 45.1	3 54.9
51	2 6.7	2 16.5	2 26.4	2 36.2	2 46.1	2 55.9	3 5.8	3 15.7	3 25.5	3 35.4	3 45.2	3 55.1
52	2 6.8	2 16.7	2 26.5	2 36.4	2 46.2	2 56.1	3 6.0	3 15.8	3 25.7	3 35.5	3 45.4	3 55.2
53	2 7.0	2 16.8	2 26.7	2 36.6	2 46.4	2 56.3	3 6.1	3 16.0	3 25.8	3 35.7	3 45.5	3 55.4
54	2 7.1	2 17.0	2 26.9	2 36.7	2 46.6	2 56.4	3 6.3	3 16.1	3 26.0	3 35.9	3 45.7	3 55.6
55	2 7.3	2 17.2	2 27.0	2 36.9	2 46.7	2 56.6	3 6.5	3 16.3	3 26.2	3 36.0	3 45.9	3 55.7
56	2 7.5	2 17.3	2 27.2	2 37.0	2 46.9	2 56.8	3 6.6	3 16.5	3 26.3	3 36.2	3 46.0	3 55.9
57	2 7.6	2 17.5	2 27.4	2 37.2	2 47.1	2 56.9	3 6.8	3 16.6	3 26.5	3 36.4	3 46.2	3 56.1
58	2 7.8	2 17.7	2 27.5	2 37.4	2 47.2	2 57.1	3 6.9	3 16.8	3 26.7	3 36.5	3 46.4	3 56.2
59	2 8.0	2 17.8	2 27.7	2 37.5	2 47.4	2 57.3	3 7.1	3 17.0	3 26.8	3 36.7	3 46.5	3 56.4

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